STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

Geology of the San Jose-Mount Hamilton Area, California

BULLETIN 157

1951

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO

STATE OF CALIFORNIA
EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO 11
OLAF P. JENKINS, Chief

SAN FRANCISCO — BULLETIN 157 — APRIL 1951

GEOLOGY OF THE SAN JOSE-MOUNT HAMILTON AREA, CALIFORNIA

By MAX D. CRITTENDEN, JR.

LETTER OF TRANSMITTAL

To His Excellency

THE HONORABLE EARL WARREN

Governor of the State of California

Sir: I have the honor to transmit herewith Bulletin 157, *Geology of the San Jose-Mount Hamilton Area, California*, prepared under the direction of Olaf P. Jenkins, Chief of the Division of Mines, Department of Natural Resources. The report is accompanied by a detailed colored lithographed map of the parts of the quadrangles covered. It also contains a number of photographs, cross-sections, and various other illustrations. Detailed descriptions are given of the rocks and their composition, structure, and history, together with the economic minerals—quicksilver, manganese, and road material—found in them. The subject of ground water conditions is also treated.

In preparing this report, the author, Max D. Crittenden, Jr., carried on his field work and laboratory studies in connection with fulfilling the requirements of his doctorate at the University of California. The project was done in cooperation with the Division of Mines and represents one of a series of such projects of mapping the geology of the State.

Respectfully submitted,

Warren T. Hannum, Director
Department of Natural Resources

November 27, 1950

CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE SAN JOSE-MOUNT HAMILTON AREA, CALIFORNIA *

By Max D. Crittenden, Jr.

ABSTRACT

The San Jose-Mount Hamilton area is in the central Coast Ranges of California, about 50 miles southeast of San Francisco; it extends from Copernicus Peak, near Mount Hamilton, to the edge of the Santa Clara Valley.

The oldest rocks exposed are arkosic sandstone and shale, and small amounts of thin-bedded chert and altered volcanic rocks, of the Upper Jurassic Franciscan formation. The Knoxville formation (Upper Jurassic) is in fault contact with the Franciscan. Large masses of serpentine and smaller plugs and dikes of gabbro and diorite intrude these sediments; glaucophane schists and their unusual mineralogical assemblages are developed locally.

As much as 5,000 feet of Oakland conglomerate(?), succeeded by fine-grained sediments of the Berryessa formation, were deposited east of San Francisco Bay; scant fossil evidence suggests that both these units are Lower Cretaceous in age. Between the Cretaceous and middle Miocene, there is an interval unrecorded in sediments, during which the dominant trends and major structural units of the Coast Ranges were blocked out. The west edge of the Diablo Range and the block now beneath the Santa Clara Valley were uplifted and stripped of Cretaceous rocks. The faults thus formed established lines of weakness which were later followed by faults with largely horizontal displacement; the narrow block between them became a persistently negative belt called the Tularcitos trough.

Seas again advanced over the area, depositing the Temblor and Monterey formations during the middle Miocene, and the Briones sandstone during the upper Miocene. Following this, the core of the Diablo Range was uplifted and folded, exposing the Franciscan formation over large areas during the deposition of the Orinda formation in the Tularcitos trough. The final and strongest folding occurred sometime during the Pliocene when rocks of the Tularcitos trough underwent strong compression and overthrusting by the Franciscan core of the range, and were elevated to become part of the Diablo Range.

During the early Pleistocene the conglomerates of the Packwood gravel and Santa Clara formation accumlated in the ancestral Santa Clara Valley. Horizontal movements on the Calaveras and Hayward faults began, cutting across the axes of earlier folds. Twice-renewed uplift of the Diablo Range brought the mountains to their present altitude.

Quicksilver deposits in Silver Creek and Oak Hills are believed to be associated with late Pleistocene to Recent volcanism. Minor deposits of manganese occur in the cherts of the Franciscan formation.

INTRODUCTION

Location. The San Jose-Mount Hamilton area is in the Coast Ranges of California about 50 miles southeast of San Franciseo. The portion mapped is on the west slope of the Diablo Range, between the latitude of 37°15′N. and 37°30′N.; it extends from a line through Copernicus Peak on Mount Hamilton west to the edge of Santa Clara Valley.

Field Work. The work was started in December 1940; about a month was spent in the field between then and June 15, 1941, and a few days were spent in January 1942. Work was resumed on weekends in October 1946, and continued full time from March 1 to June 1, 1947, and from November 20, 1947, to May 1, 1948.

Mapping was begun using the topographic maps of the U. S. Geological Survey on a scale of 1:62,500. After the war, maps made by multiplex by the U. S. Army Engineers became available, and work was continued on this base. In the spring of 1947, aerial photographs on the seale

* Submitted in partial fulfillment of the requirements for the degree Doctor of Philosophy, University of California, Berkeley, California. Manuscript submitted for publication May 1949.

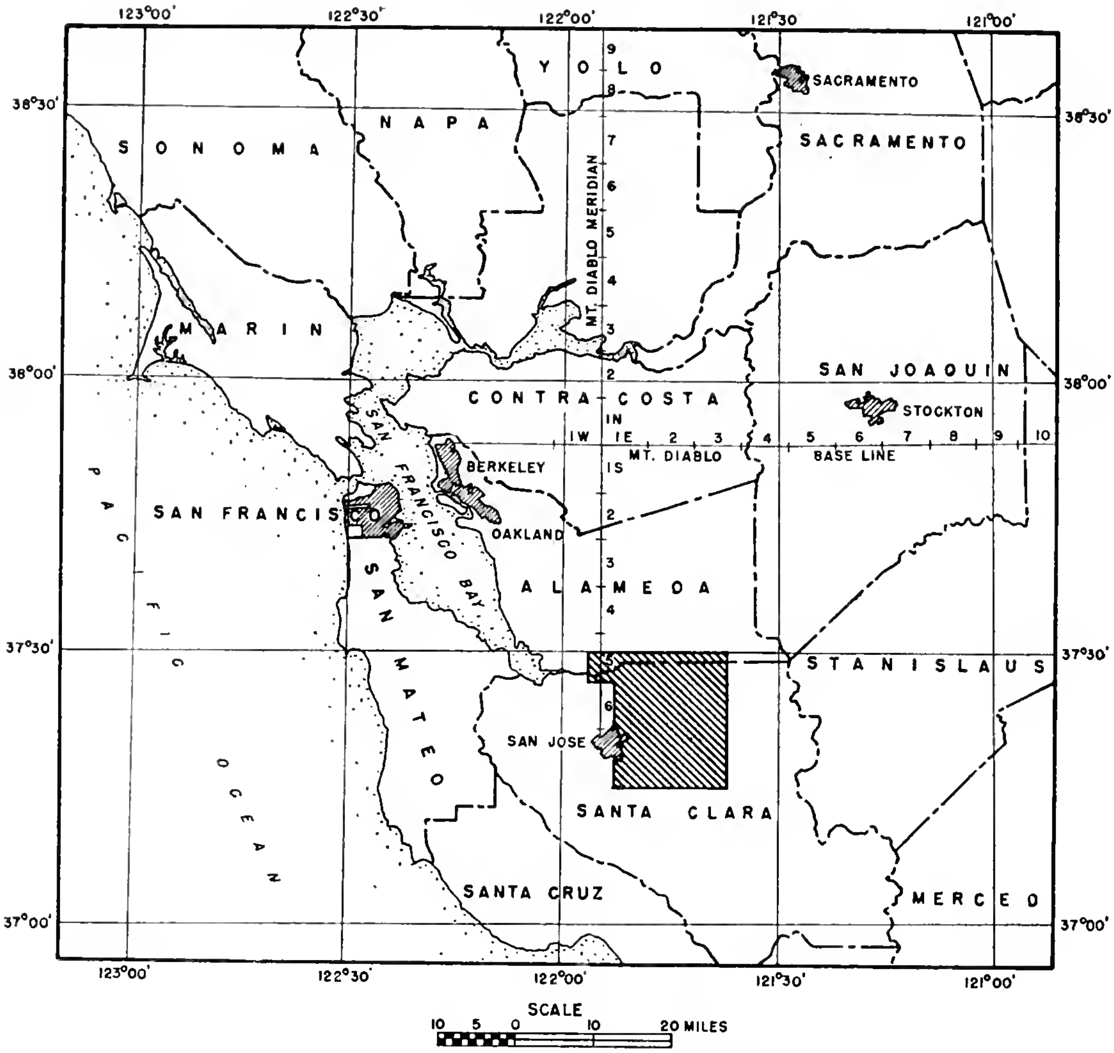

FIGURE 1. Index map showing location of the San Jose-Mount Hamilton area

of 1:20,000 were obtained, and most of the recent work has been done directly on the photos. The original maps, aerial photographs, and specimens are on file in the Department of Geology of the University of California at Berkeley.

Acknowledgments. It is a pleasure to acknowledge the courtesy and helpfulness of the many residents of the area who permitted the author to drive or walk over their property. He is particularly indebted to Mr. Wright of the Grant Ranch, Mr. Douglas C. Alexander and Mr. Paul C. Hoover of Rancho Los Huecos, Mr. Shelton of the Richmond Ranch, Mr. W. S. Holmes of the Paradise and Holmes Ranches, Mrs. A. F. Kirschner, Mr. N. A. Eckert, and Mr. Walter Yount of the San Francisco Water Department, Mr. E. O. Wool, Mr. John Rogers and Mr. John Tiernan; and Mr. Lee Ogier for the genuine interest and hospitality I enjoyed at the Ogier Ranch on Alameda Creek.

To Dr. Wayne E. Kartchner, of San Jose State College, gratitude is expressed for the loan of a petrographic microscope. Acknowledgment is also made to Prof. N. L. Taliaferro, under whose direction the work was done, for his interest and assistance.

To the regents of the University of California, the author is indebted for financial assistance during 1947 and 1948 which made possible the completion of the work.

Geography. The San Jose-Mount Hamilton area is on the west edge of the Diablo Range, about 50 miles south-southeast of San Francisco. Santa Clara Valley, a continuation of the trough of San Francisco Bay, slopes upward imperceptibly to the south, attaining an altitude of 184 feet at Edenvale. To the east, broad, low alluvial fans with a slope seldom exceeding 100 feet per mile, reach altitudes of 300 and 500 feet at the foot of the mountains. Here and there the orchards and fields of the Santa Clara Valley are interrupted by isolated hills such as Oak Hills south of San Jose, whose rocky bedrock surfaces indicate that they are the tops of ridges or hills only partly covered by alluvium.

The mountains rise abruptly from the alluvium to altitudes of 1,000 to 2,000 feet. Their average slope is 600 to 1,000 feet per mile. From Warm Springs to Evergreen the mountain front is a relatively smooth slope, broken only by the canyons of Arroyo de Los Coches, Berryessa Creek, and Penitencia Creek. Except for those larger streams, the creeks flowing down the surface are short, steep, and intermittent, and are in shallow, poorly developed canyons. The major streams of the area form a modified trellis pattern with a northwest trend. The canyons are very steep, reaching a maximum in Arroyo Hondo, which is nearly 3000 feet deep west of Mount Day. Most of the area west of Mount Hamilton drains northward through Calaveras Valley or Arroyo Hondo, into Alameda Creek, which reaches San Francisco Bay through Niles Canyon. A small area near San Felipe Valley drains south into Coyote Creek, which flows into the Santa Clara Valley near Morgan Hill.

Immediately east of the Santa Clara Valley is a fairly continuous ridge, separated from the rest of the mountains by the Calaveras fault. East of Warm Springs this ridge rises to an elevation of 2608 feet, forming Monument Peak. It continues south to Los Buellis Hills and the high points along Sierra Road, but is cut through completely by Alum Rock Canyon of Penitencia Creek. To the south, it continues from Alum Rock triangulation station through Masters Hill and the ridge east of Evergreen. East of this ridge, a series of aligned creeks and valleys, extending through Calaveras Valley, Halls Valley, and San Felipe Valley, marks the course of the Calaveras fault zone. This prominent feature has provided reservoir sites at three places within the area mapped, and in Coyote reservoir a short distance to the south of the area.

Viewed from a high point like Mount Lewis, near the north edge of the area, the ridge crests rise successively higher east from the valley toward Mount Hamilton, Mount Isabel, Mount Day, and Black Mountain, all about 4,000 feet in elevation. East of here, the average elevation decreases, and the area slopes into the interior valleys of upper Isabel Creek and Arroyo Bayo.

The climate of the area is of Mediterranean type, with mean temperatures ranging from about 40 to 70 degrees. Average rainfall is 16-17 inches in San Jose and 32 inches at Mount Hamilton. Most of the rainfall occurs during the months of December, January, and February; the months of June, July, and August are commonly almost dry.

The smooth lower slopes of the mountains are mostly cultivated or are open grassland. Steep dry slopes are commonly covered by a sagebrush association characterized by Artemisia and the bush monkey flower (Mimulus). Within the range, the southwest slopes and ridgetops are open and grassy, but scattered oaks are abundant; the north-facing slopes and deep canyons are covered with brush or woods in which various types of oak predominate. The summits of some of the higher ridges, such as Mount Lewis and Mount Day and the southern parts of the San Felipe Hills have developed local mixed forests of coulter and yellow pine and black oak. The interior of the Diablo Range north and east of Mount Hamilton is dominated by a dense cover of chaparral, in which manzanita (Arctostaphylos), buckthorn (Rhamnus), chamise (Adenostoma), mountain mahogony (Cercocarpus), and Baccharis are common types.

The flora of the Mount Hamilton range has been studied by Sharsmith,[1] who discusses the effect of lithology on its development. This relationship is most striking in the case of serpentine which usually shows a characteristic flora consisting of species which are to be found in many dry rock areas, species which occur mostly on serpentine, and a few species whose occurrence is restricted to serpentine. One example is the long narrow area of serpentine northwest of Mount Hamilton which is characterized by a thick growth of chaparral, contrasting strongly with the surrounding open grassland and forests. The influence of the stratified rocks on vegetation is less marked than in many areas of the Coast Ranges.

Roads are abundant and fairly closely spaced throughout most of the area. Several paved county roads extend up the mountain front east of Santa Clara Valley. East of this ridge, fire control and ranch roads extend along most of the ridges. Only a few of the deep canyons are accessible by road. The area of Calaveras Dam is accessible either from Milpitas or Sunol. The highway from San Jose to Mount Hamilton provides a good section across the entire area near the center. The Dry Creek road southeast of Evergreen and ranch roads leading east to Isabel Valley from San Felipe Valley make access to this area relatively easy.

Previous Work. The earliest geological study of the San Jose-Mount Hamilton area was made by J. D. Whitney in 1865 as part of the Geological Survey of California.[2] The sandstone, chert, and metamorphic rocks of the Franciscan formation were recognized and distinguished from the fossiliferous Tertiary rocks in Alum Rock Canyon; serpentine and its differentiates were pointed out.

The first detailed study was by students of the Stanford Geological Survey in 1905 and 1906, in 1911 and 1912, and in 1922 and 1923. Two short papers, the first dealing with stratigraphy [3] and the second with petrography [4] appeared about this time. E. C. Templeton also completed a study of the San Jose quadrangle in 1911.[5] All this early work was compiled and extended by F. P. Vickery [6] whose work is the first general

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[1] Sharsmith, Helen K., The flora of the Mount Hamilton range of California: Am. Midland Naturalist, vol. 34, no. 3, pp. 289-367, 1945.

[2] Whitney, J. D., Geological survey of California, vol. 1, pp. 47-52, Philadelphia, Sherman and Company, 1865.

[3] Crandall, Roderic, The Cretaceous stratigraphy of the Santa Clara Valley: Am. Jour. Sci., 4th ser., vol. 24, p. 41, 1907.

[4] Carey, E. P., and Miller, W. J., The crystalline rocks of the Oak Hills near San Jose: Jour. Geology, vol. 15, pp. 161-166, 1907.

[5] Templeton, E. C., The geology and stratigraphy of the San Jose quadrangle, unpublished Doctor's Thesis, Stanford University, 1913.

[6] Vickery, F. P., The structural dynamics of the Livermore region: Jour. Geology, vol. 33, pp. 608-628, 1925.

report on the area to be published. Willis[7] mentions briefly the physiographic features of the Mount Hamilton Range in a discussion of the physiography of the Coast Ranges.

The structural dynamics of parts of the Hayward and Calaveras fault zones have been discussed by B. L. Clark.[8] The general geology of the Diablo Range, and a section through the Alum Rock Canyon area were recently published by Taliaferro.[9] Interesting mineralogical occurrences in the area have been described by A. F. Rogers.[10]

PHYSIOGRAPHY

General Statement. The physiographic development of the San Jose-Mount Hamilton area is approaching the mature stage. Ridges are commonly narrow, canyons are steep, and streams are approaching grade in their lower reaches. The development is far from uniform, however, and complicated by many structural irregularities. It was immediately apparent in the field that the present form is the product of more than one period of erosional development, and that its features have been inherited from older cycles of erosion only partly preserved.

Present Erosion Cycle. Canyon cutting, and rapid headward growth of stream valleys now is the dominant process over almost all the area. Arroyo Hondo, Smith Creek north of the Smith Creek Ranger Station, Isabel Creek west of its junction with Bonita Creek, and Alameda Creek northwest of the Ogier Ranch are all youthful streams, flowing in steep narrow canyons. There is no suggestion of recent lateral cutting. From Poverty Ridge to the San Felipe Hills, the streams flowing into Arroyo Hondo and Smith Creek are developing headward rapidly by gullies cut in the smoother ridge tops. Similar gullies are found on the divide between Dry Creek and San Felipe Valley where the streams flowing toward the south are cutting into smooth slopes and alluvium-filled valleys. The headwaters of Arroyo Aguague north of Halls Valley are steep and narrow, and deep gullies were being cut in the mature surfaces of Halls Valley before they were interrupted by damming.

Older Broad Valleys. Evidence for an earlier period of canyon cutting is clearly discernable in many places. Up Arroyo Hondo, for example, near its junction with Calaveras Valley, a distinct break in the slope of the walls is observable, and the profile of the interlocking spurs outlines a much less rugged canyon whose floor was about 1000 feet above the present stream. Distinct benches preserved on the spurs east of the canyon are accordant with the smooth-surfaced ridge between Isabel Creek and Smith Creek. Farther upstream these benches disappear, and the canyons are noticeably less rugged. Smith Creek, east of San Felipe Hills, flows in a steep but not precipitous canyon, and has

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[7] Willis, Robin, Physiography of the California Coast Ranges: Geol. Soc. America Bull., vol. 36, no. 4, pp. 641-678, 1925.

[8] Clark, B. L., Tectonics of the Coast Ranges of middle California: Geol. Soc. America Bull., vol. 41, pp. 747-828, 1930.

[9] Taliaferro, N. L., The Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, no. 2, pl. 2, section 9, 1943.

[10] Rogers, A. F., An interesting occurrence of manganese minerals near San Jose, California: Am. Jour. Sci., 4th ser., vol. 48, pp. 443-449, 1919.

Rogers, A. F., The crystallography of hydromagnesite: Am. Jour. Sci., 5th ser., vol. 6, pp. 37-47, 1923.

Rogers, A. F., Euhedral magnesite crystals from San Jose, California: Am. Mineralogist, vol. 8, no. 8, pp. 138-140, 1923.

Rogers, A. F., Kempite, a new manganese mineral from California: Am. Jour. Sci., 5th ser., vol. 8, pp. 145-150, 1924.

developed narrow valley flats that are most marked in Horse Valley. Isabel Creek undergoes a similar change of character at the east edge of the map as it approaches Isabel Valley; Alameda Creek in its course between Valpe Ridge and Packard Ridge is similarly open. The relatively open, smooth topography of Packard and Seeboy Ridges is probably typical of that throughout the range during this cycle of development.

Oak Ridge Surface. Traveling along the crest of Poverty Ridge, or Oak Ridge, one is struck immediately by the extensive areas of flat or gently rolling topography, which are remnants of a still older period of erosion. The smooth surfaces end abruptly at the edges of steep canyons, and here and there have given way, as in the great Oak Ridge slide. Scattered remnants of this old surface are preserved throughout the area, and it is strikingly evident in the profile of Oak Ridge as seen from the west, near the summits of Mount Day and Black Mountain, and on the summit of Mount Lewis. Extending these remnants across the intervening valleys, one can reconstruct a gently sloping mature surface characterized by smoothly rounded contours, and with a relief that probably did not exceed 1,500 feet. There is no evidence that the surface continues east of Mount Lewis and Black Mountain; however, well-developed flats continue south on both sides of Smith Creek, and grade into the rolling topography of the San Felipe Hills. Although correlation across the Calaveras fault zone is somewhat uncertain, smooth surfaces on the east side of Monument Peak and along Sierra Road west of Los Buellis Hills are tentatively regarded as extensions of the Oak Ridge surface.

Silver Creek Surface. The summit of the ridge between Silver Creek and Santa Clara Valley has a remarkably smooth and level surface that is best developed south of the area mapped. East of Edenvale, the surface is less well developed, and consists of rounded hills with accordant summits. This surface is separated from the main part of the range by two large fault zones, both of which have been active recently. For this reason, it cannot be correlated definitely with either of the other surfaces.

Isolated Surfaces. Two small isolated areas of old-age topography occur along the Calaveras fault zone. The most prominent of these is a gently sloping surface at the south end of San Felipe Valley. This almost plane surface is bounded on the west by a branch of the Calaveras fault system, and on the east by San Felipe Creek. It is being dissected by gullies from all sides, but particularly from the east and south. Another area of subdued relief is that extending north from Halls Valley along the Calaveras fault zone. This gently rolling surface rises slowly from Halls Valley northward, is interrupted by Arroyo Aguague and continues into the area around the Haskins triangulation station. This continuity suggests strongly that these surfaces are downwarped parts of the Oak Ridge surface. The most striking feature of these areas, however, is the tilting and warping they show, and the change in the drainage pattern which has resulted. The surface near San Felipe Valley slopes northward, but is being dissected by a southward-flowing stream, San Felipe Creek. In Halls Valley, the surface slopes gently southward and the headwaters of San Felipe Creek are being pirated rapidly by the steeper, shorter Arroyo Aguague.

Correlation of Erosion Cycles and Recent Sediments. The erosional features described in the preceding paragraphs indicate that the mountains east of San Jose have been abruptly elevated twice within relatively recent geological time. Moreover, the magnitude of the displacements is sufficient to suggest that these events should also be recorded in the sediments accumulating within and around the margins of the adjoining Santa Clara and Livermore Valleys.

The present cycle of erosion can be correlated readily with alluvial cones which extend out from the mouths of the main streams and which coalesce to form a broad alluvial apron along the whole mountain front. These deposits, which are relatively coarse near the mountains and contain some coarse debris well out in the valley, are presumed to rest on older sediments, which are somewhat finer grained. Logs of deep wells in San Jose show a marked decrease in amount of gravel near the bottom.

The older valley stage of erosion is tentatively correlated with the period of sedimentation which produced the Santa Clara formation. This correlation is based largely on the relations observed near the mouth of Penitencia Creek and must be regarded as highly tentative until data from other areas are accumulated. The multiple transverse profile of Penitencia Creek through Alum Rock Canyon is evident in the view down the canyon (pl. 6*B*) and in the ridge profile (fig. 2, A-A′, B-B′, C-C′) obtained from the map (pl. 1). The older valley surfaces were projected to the center of the stream for each profile, giving three points on the old broad valley stream. These points were then transferred to the longitudinal profile (fig. 2) whose emergence at the front of the range indicates roughly the base level during this stage of stream cutting. The older valley stream apparently reached the front of the range at an altitude of about 1100 feet. This is reasonably close to the level of the highest exposures of the Santa Clara formation at 1300 feet. The most serious difficulty with this correlation is the persistent east dip of the Santa Clara formation which averages about 10 degrees, but locally may be as much as 30 degrees. If this is attributed to tilt, it must have affected the entire block, including the Oak Ridge surface. However, there is no evidence of eastward tilting of that surface, so either the dips are initial or the Santa Clara formation is older than any of the erosion surfaces preserved in the area. The latter alternative seems untenable inasmuch as the Santa Clara formation is resting on the eroded mountain front which truncates the Oak Ridge surface. It is suggested that the Santa Clara formation was rapidly deposited by a large stream which piled material against the sloping mountain front. This process could account, at least in part, for the dips observed.

There are no known high-level recent sediments in the Santa Clara Valley which might be correlated with the Oak Ridge erosion surface. However, the gentle northward slope of the surface on Oak Ridge and Valpe Ridge suggests that this surface might be correlated with some of the relatively recent sediments in Livermore Valley. Figure 3 shows the uniformity and extent of the surface developed on Oak Ridge, Valpe Ridge, and the slopes leading into San Antonio and Vallecitos Creeks in the southern end of the Pleasanton quadrangle. It also shows the relationship of this surface to the gently tilted Livermore gravel and lends some support to the theory that the surface on which the gravel was deposited is an extension of the Oak Ridge surface. Serious difficulty is encountered,

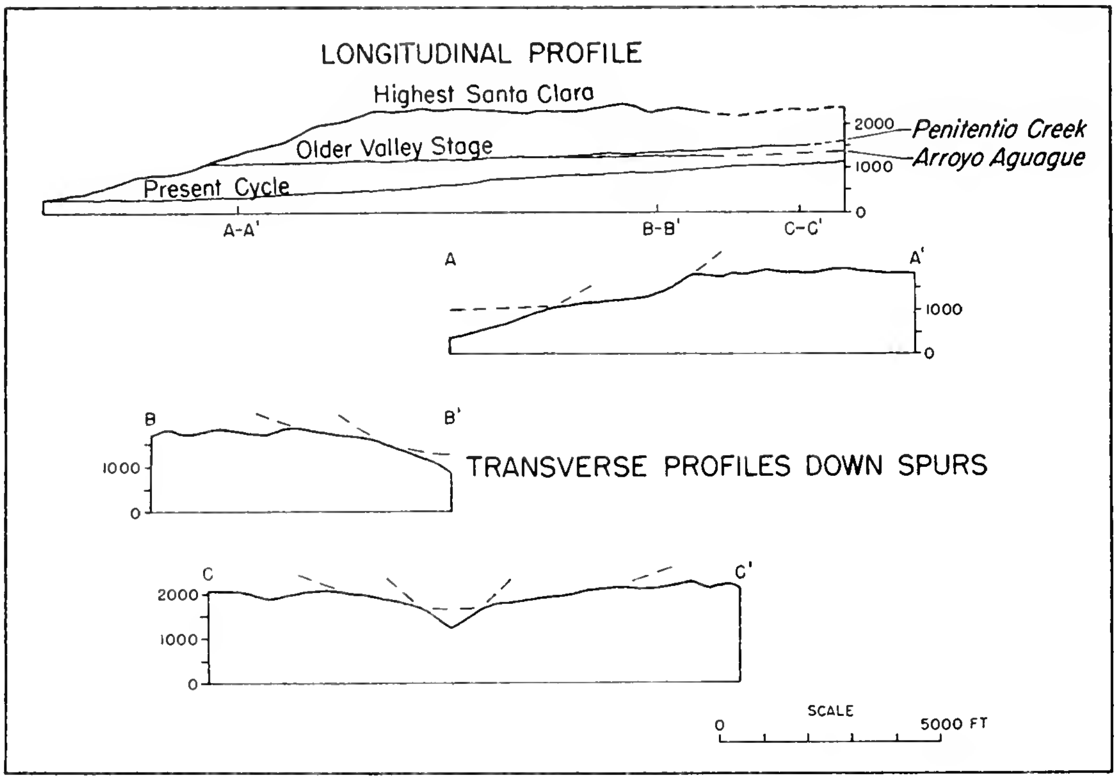

FIGURE 2. Profiles of Penitencia Creek in Alum Rock Canyon

however, if the Livermore gravel is all one unit, as mapped by Huey,[11] and is involved in major folding in Corral Hollow and in faults in the Hetch Hetchy tunnel which have no topographic expression. However, Harding [12] separates the Livermore gravel in the southern part of the Pleasanton quadrangle into two units: the older, "Pliocene A," is folded with the Briones and older formations, and contains white limestone, volcanic ash, silty shale, and sandstone; the younger formation, "Pliocene B," consists of silt and clay interbedded with coarse conglomerate containing much Franciscan debris. These gravels dip north toward Livermore Valley at a low angle, and are warped and faulted, but not folded with the Pliocene and older rocks. These rocks may conceivably have been deposited during the erosional interval represented by the Oak Ridge surface.

STRATIGRAPHY

The sedimentary rocks of the San Jose-Mount Hamilton area, like those of most of the central Coast Ranges of California, range in age from Upper Jurassic to Recent. However, the number of formations of Tertiary age is not as large as in many other areas. With one exception, the formational names used are those already in use in adjoining areas. The name Berryessa formation is introduced to denote the Lower (?) Cretaceous shales which have been called Chico by earlier workers.

The area provides very few opportunities for detailed stratigraphic study. Because of incomplete exposures and many fault contacts, it has

[11] Huey, Arthur S., Geology of the Tesla quadrangle, California: California Div. Mines Bull. 140, 1948.

[12] Harding, J. W., Geology of the southern part of the Pleasanton quadrangle, unpublished thesis for master's degree, University of California, Berkeley, 1943.

not been possible to measure an unbroken section of any of the formations exposed. Fossils are abundant in only one formation, the upper Miocene Briones sandstone.

Jurassic System

Franciscan Formation

Distribution and Thickness. The Franciscan formation crops out, or is present beneath the alluvium, in almost two thirds of the area mapped. East of the Calaveras fault zone it is exposed over more than 100 square miles, and this is only the western edge of the great area of Franciscan rocks which extends unbroken for 25 miles to the east, and which forms the core of the Diablo Range. A smaller area of Franciscan crops out southeast of San Jose, and continues northwest beneath the alluvium of the Santa Clara Valley to join the Franciscan rocks exposed in the San Francisco peninsula and the islands of San Francisco Bay. Between the two areas of Franciscan rocks is a band of Tertiary and Cretaceous rocks which is bounded by major faults. A few very small slivers or blocks of Franciscan occur outside these areas along the bounding faults.

No new evidence concerning the thickness of the Franciscan formation has been found in the San Jose-Mount Hamilton area. Neither its base nor its top is exposed, nor is it possible to delineate the structure with certainty. The general scarcity of chert lenses or extensive basalt flows gives less indication than usual of the general attitude and the position within the formation. The thickest continous section in the area mapped is just east of the Calaveras fault, where at least 6,000 feet of beds are exposed. There is no evidence of large faults cutting this limb of the fold, but the lack of stratigraphic control makes even this uncertain. In any case, 6,000 feet is a minimum thickness, and is probably much less than the total.

Templeton [13] reported a thickness of 15,000 to 20,000 feet in the San Jose and Mount Hamilton quadrangles, but did not indicate how or where the figure was reached. Tolman [14] also reported a thickness of 15,000 feet, apparently along a line extending from Oak Ridge, in the northern part of this area, to Corral Hollow in the Tesla quadrangle. He went so far as to divide the Franciscan into three formations, a sandstone and shale in Corral Hollow as the lowest unit, shale and chert called "Corral Hollow shales" as the middle unit, and the "Oak-ridge sandstone" as the upper unit. The writer's observations near Oak Ridge indicate that the structure there is obscure, and consists of several folds. These structures are so uncertain that no attempt was made to estimate a thickness. Huey [15] has described the section near Corral Hollow, and found no evidence that the Franciscan formation can be divided successfully there.

The information available concerning the thickness of the Franciscan was summarized recently by Taliaferro: [16]

> "It is impossible at present to give any definite figures for the thickness of the Franciscan . . . however there are excellent and continuous sections at least 10,000 feet thick . . . (and) the writer does not believe that an estimate of 25,000 feet . . . is excessive."

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[13] Templeton, E. C., General geology of the San Jose and Mount Hamilton quadrangles (abstract): Geol. Soc. America Bull., vol. 24, p. 96, 1913.

[14] Tolman, C. F., A geological report on the Coyote dam-site—a report to the Santa Clara Valley Water Conservation District (unpublished), 1934.

[15] Op. cit.

[16] Taliaferro, N. L., The Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, no. 2, p. 155, 1943.

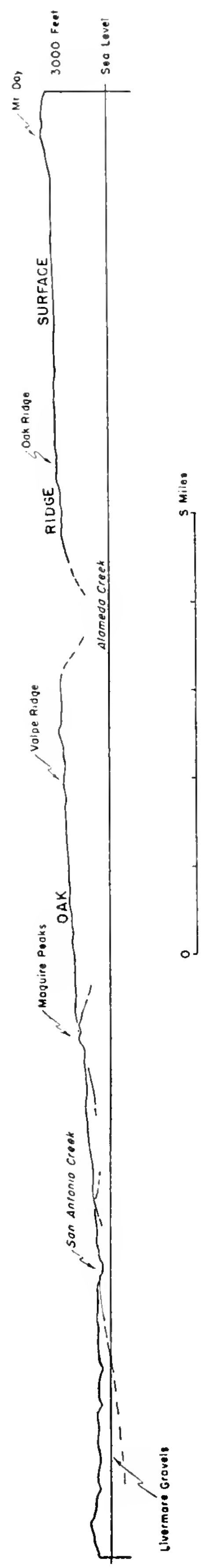

FIGURE 3. Profile of Oak Ridge and Valpe Ridge showing gentle northward slope and relationship to the Livermore gravels

The Franciscan formation in this area consists of sandstone, siltstone, shale, conglomerate, radiolarian chert, and altered basaltic and andesitic lavas and agglomerates. These types are intruded by basalt and andesite and by serpentinized ultrabasic rocks, diorite, gabbro, and diabase. Glaucophane-bearing metamorphic rocks occur locally at the contact of bodies of serpentine and in isolated areas a few feet to a few hundred feet in diameter.

Sandstone and Shale. Sandstone, and smaller amounts of interbedded siltstone and shale, comprise more than 90 percent of the Franciscan formation in this area. The total thickness of these rock types cannot be estimated, but there is at least 6,000 feet exposed east of the Calaveras fault, and the total thickness is undoubtedly much greater. The typical fresh sandstone is a dark-gray medium-grained massive rock, cut by many tight and almost invisible joints and fractures filled with calcite. When weathered, it is greenish gray, greenish brown, or buff, and the joints are so closely spaced that it is often impossible to determine the attitude except where the sandstone is interbedded with shale or where the exposures are unusually good. The rock is commonly rather thick bedded, but thin-bedded sandstone and siltstone occur in many places.

The sandstones of the Franciscan formation were studied and described in detail by Davis [17] and by Taliaferro.[18] Little to augment these studies was done in connection with this work. The sandstones can easily be distinguished from those of other formations by the almost ubiquitous occurrence of flakes of pearly transparent muscovite. The presence of this mineral and the absence of brown wrinkled biotite provided a reliable means of distinguishing Franciscan sandstone from sandstone in the Berryessa formation, for example. Several other specimens of Franciscan sandstone from widely separated localities all contained more or less of this pearly muscovite. An attempt to separate this mineral from crushed and sized material by centrifuging in heavy media proved unsuccessful. It was impossible to isolate it from accompanying chlorite in a reasonable number of separations. In a fresh specimen from the Alameda Creek tunnel of the San Francisco Water Department and in a specimen from the Eel River collected by C. M. Gilbert, the mica showed N_p of $1.600\pm$, and a 2 V (negative) of 36°-42°.

A mineral analysis of this same fresh sandstone is contained in table 1. There are several striking differences between the mineral content of the specimen from Oak Ridge and the average listed. Some of this difference is a result of the method of treatment; acid treatment of the other 17 samples explains the absence there of the chlorite, biotite, muscovite, and sphene found in the San Jose sample. Hand magnet separation of iron from the San Jose sample accounts for the absence of the magnetite found elsewhere. The most significant difference is in the quartz-feldspar ratio. The ratio of the San Jose sample is 0.47, that of the average for 17 sandstones is 1.51. The only samples listed by Taliaferro,[19] with a ratio approaching this were numbers 2 and 4, whose ratios were 0.64 and 0.55 respectively. The count of the light minerals listed in table 1 was made by observation of interference figures under high power, and was later checked with the universal stage.

[17] Davis, E. F., The Franciscan sandstone: Univ. California, Dept. Geol. Sci. Bull., vol. 11, pp. 235-432, 1912.

[18] Taliaferro, N. L., The Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, no. 2, pp. 109-219, 1943.

[19] Op. cit., p. 134, 1943.

Table 1. Mineral content of fresh Franciscan sandstone.

	Sample a		Sample b
Light minerals			
Quartz	22	32	56.2
Feldspar	47	68	37.1
Rock fragments and composite grains	31	--	6.7
	100	100*	100.00
Heavy minerals	Not acid treated		Acid treated
Chlorite	37		3.5
Biotite	25		1.2
Leucoxene	17		9.8
Sphene	9		7.7
Zoisite-epidote	2		5.2
Apatite	2		----
Zircon	1		5.0
Tourmaline	1		1.8
Hornblende (green)	1		2.0
Kyanite	1		----
Picotite	1		----
Composite and indeterminate grains	3		51.8
Magnetite	--		5.1
Pyrite	--		3.1
Garnet	--		3.0
	100		99.2

Sample a: From Alameda tunnel, Oak Ridge, San Jose quadrangle.
Sample b: Average of 17 sandstones from Coast Ranges (Taliaferro, N. L., The Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, p. 135, 1943.
* Quartz and feldspar recalculated to 100%.

A single mineral analysis like that given above is of little significance by itself, but it does show the range of composition of these rocks to be considerable, The assemblage of heavy minerals is not unusual with the exception of kyanite which is rather rare. Three or four grains were seen in each mount.

Conglomerate. Only a few outcrops of Franciscan conglomerate were found in the area mapped. The largest of these is on the north side of Isabel Creek 1½ miles north of Mount Hamilton. It is an outcrop about 100 feet across, consisting of well-rounded smooth cobbles and pebbles an eighth of an inch to 10 inches in diameter. The lithologic types observed include black quartzite or recrystallized chert, coarse-grained quartz and feldspar porphyries of several types, and a few granitic or dioritic rocks.

A second occurrence is in Los Buellis Hills. This also is coarse cobble conglomerate containing in approximate order of abundance, dark quartzite or chert, various porphyries, sandstone, and a few gneissic granitic rocks. A third occurrence 1.1 miles S. 50° E. of the Ogier Ranch is of similar character, but with a more quartzitic matrix. Out of 25 pebbles counted, there were 17 of recrystallized chert, mostly brownish but some black and some white, 5 of quartzite, 2 of sandstone, and 1 of vein quartz. One other lens of conglomerate was found, in a cut along the road running along the crest of the San Felipe Hills at a point 0.8 of a mile south of the road from San Felipe Valley to Horse Valley.

Chert and Contemporaneous Volcanics. Cherts are abundant in only two relatively small areas, one east of Alum Rock Canyon, the other southeast of Mount Hamilton. Lenses of chert up to 50 feet thick and a few hundred feet long occur at a few other places. These rocks are the rhythmically bedded chalcedonic radiolarian cherts characteristic of the Franciscan, which have been described by Davis [20] and Taliaferro.[21] The most common type is thin-bedded red, brown, green, or white chert with thin partings of shale. There are many unusual and striking varieties, however, of purple, yellow, blue, or black chert, which are sought by amateur rock collectors for polishing. Most of these show brecciation, recrystallization, or development of new minerals of hydrothermal origin. The more altered types grade into glaucophane schists. Chert showing rather unusual alteration of this type was found in place east of Los Buellis Hills, on the Santa Teresa Hills east of Edenvale, and as float in many of the larger streams. It is particularly abundant in Isabel Creek, north of Mount Hamilton.

The restricted occurrence of both chert and altered volcanic rocks in the area east of the Calaveras fault makes the closeness of their association all the more striking. Both the cherts and the volcanics occur as lenses enclosed in sandstone and shale, and where one is found, the other is almost always present.

The Franciscan greenstones of the San Jose-Mount Hamilton area are mostly rather small bodies, whose character, composition, and origin is badly obscured by alteration. Rocks in which the original minerals can be recognized are rare. It is for this reason, plus the fact that many types and varieties occur, that the term "greenstone" is used. It does not imply that the rocks are schistose. Pillow structure, poorly developed, was observed in only one or two places. Most outcrops show considerable shearing and internal fracturing, even though they may have been relatively massive when formed.

The typical greenstone is a dark-green to black fine-grained rock so badly fractured and veined by quartz, calcite, and thin films of manganese and iron, that it is quite difficult to obtain a fresh break. When exposed, a fresh surface commonly reveals only a fine-grained dull-green aphanitic rock in which no minerals can be recognized. In some specimens scattered phenocrysts, amygdules, or vesicles can be distinguished, but considerable search is required to find them.

A somewhat unusual igneous rock, a quartz keratophyre, is enclosed in the Franciscan formation near the south edge of the map (pl. 1), just east of the line of section E-E′. It is not an altered basic igneous rock, but appears as "greenstone" on the map because its identity was not recognized in the field. In the hand specimen, the quartz keratophyre is a greenish to brownish-gray rock with a marked porphyritic texture except where very badly altered. It weathers yellowish to reddish brown, and at places along the contact with serpentine can only with difficulty be distinguished from the typical silica-carbonate rock. Pinkish phenocrysts of feldspar up to 2 millimeters in diameter, and epidote-chlorite masses pseudomorphous after ferromagnesian minerals, are evident. Most of the exposures are massive; a few are vesicular, the cavities being lines with minute euhedral crystals of quartz and magnetite. Two thin

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[20] Op. cit., pp. 235-432.

[21] Taliaferro, N. L., The relation of volcanism to diatomaceous and associated siliceous sediments: Univ. California Dept. Geol. Sci. Bull., vol. 23, pp. 1-56, 1933.

sections were examined. They both contain thick complexly twinned prisms of albite (An 7) about 2 millimeters in length, and a few irregular grains of quartz, most of them less than 1 millimeter in diameter. The groundmass is separated into irregular "patches" about .25 of a millimeter in diameter by a network structure of dull yellow-green chlorite. Each patch consists of an irregular area of optically continuous quartz, or micrographic intergrowth of quartz and feldspar. Rocks of this type occur in many parts of the world [22] but so far as known have not been described from the Franciscan formation.

Manganese Deposits. Several small deposits of manganese have been found within the San Jose-Mount Hamilton area. Like almost all the deposits in the Coast Ranges of California, these are closely associated with Franciscan chert and greenstone. The detailed relations of the manganese ore to the surrounding chert are not well exposed in any of the deposits, but the areal association of the manganese with the chert and greenstone is shown on plate 1. The extent and genetic significance of this relationship has been discussed by Taliaferro [23] and by Trask, Wilson, and Simons.[24]

Most of the deposits are small, and one finds little but low grade oxides exposed now. Here and there, however, fragments of primary material remain, beneath a coating of fresh black oxide. The "primary ore" from the Miller Ranch deposit just below Sierra Road on the north slope of Alum Rock Canyon is a mixture of rhodochrosite and hydrous silicates. Its specific gravity is 3.8 and it may contain as much as 35 percent manganese. With increasing amounts of silica, such material grades into manganiferous chert and finally into normal chert. Locally there are small amounts of a black mineral resembling braunite.

Serpentine and Its Differentiates. Serpentinized ultrabasic rocks are of limited extent in the area east of the Calaveras fault. Except for a small sill near Calaveras Dam, the only large exposure is in Long Branch north-northwest of Mount Hamilton. This appears to be part of a single sheet, exposed for a distance of 4 miles, and about 1500 feet thick near the south end. In general it appears to be concordant with the surrounding rocks, though their structure is not entirely clear. The rock is a highly sheared soapy variety of serpentine in which most traces of original minerals have been destroyed.

The largest exposures of serpentine in the area mapped are in the ridge between the Silver Creek fault and Edenvale, and in its extension, the partly buried ridge whose exposed summit forms the Oak Hills near Lick. Serpentine is so extensive in much of this area that its relations to the surrounding rocks are not clear except after mapping a considerable area. In the center of the Santa Teresa Hills, there are several distinct sills of serpentine, ranging from a few feet to a few hundred feet in thickness, enclosed in sandstone and shale.

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[22] Gilluly, James, Keratophyres of eastern Oregon and the spilite problem: Am. Jour. Sci., 5th ser., vol. 29, pp. 225-252, 336-352, 1935.

[23] Taliaferro, N. L., The Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, pp. 109-219, 1943. . . . and Hudson, Frank S., Genesis of the manganese deposits of the Coast Ranges of California: California Div. Mines Bull. 125, pp. 277-332, 1943.

[24] Trask, P. D., Wilson, I. F., and Simons, F. L., Manganese deposits of California, a summary report: California Div. Mines Bull. 125, pp. 51-215, 1943.

In these gently rolling hills, almost all of the serpentine outcrops form fields of irregular boulders whose rough surface contrasts strongly with the smooth grassy areas underlain by Franciscan sandstone and shale. Because of this, the broad pattern of areal distribution is immediately apparent, and can be plotted with ease on aerial photographs or topographic maps. The outcrops in an area of serpentine weather to dark-green or brown cavernous masses, whose most prominent structures are the more resistant quartz veinlets or silicified areas, and which reveal little about the structure of the serpentine body as a whole. Fresh exposures in rail or road cuts often reveal innumerable shear zones of which there is no surface expression. Here and there, however, reef-like masses of strongly sheared serpentine crop out.

Several distinct varieties of serpentine may be seen in a hand specimen. Among the more striking are intensely sheared dark-green or bluish rocks whose surfaces are almost always slickensides; dense, massive, dark, greenish rocks cut by veins of fine-grained jade-green porcelaneous serpentine; dense dark-colored rocks cut by veinlets of chrysotile which may be large and widely spaced, or may form a fine network or mesh structure; and dense dull-green rocks with scattered flakes of antigorite (bastite) pseudomorphous after pyroxene.

An interesting exposure of relatively unaltered basic and ultrabasic rocks was found in a quarry in the east edge of the Oak Hills, near San Jose. This occurrence was described by Carey and Miller,[25] and the following description is taken largely from their work. The oldest rock exposed is serpentine which, with increasing amounts of diallage, grades into olivine pyroxenite or locally diallagite; with increasing amounts of feldspar to olivine gabbro. Locally with an increase in hypersthene, the rock grades into norite, or with an increase in hornblende, it grades into hornblende gabbro. Cutting all these rock types are at least two sets of diorite dikes, an older set nearly vertical, cut in turn by a younger set that dips flatly northwest. The borders of the dikes are mostly rather fine-grained and many of the cores are so coarse as to approach a pegmatitic texture. Exposures outside the quarry are poor, and reveal little about the extent of the gabbroic rocks or the diorite dikes.

Many smaller bodies of diorite, diabase, and gabbro crop out within the areas mapped as serpentine (pl. 1). The usual outcrop is a rounded knob or a pile of boulders 5 to 20 feet in diameter, projecting several feet above the surrounding area. Its contacts with the enclosing serpentine are seldom visible in natural exposures, but the general relations suggest that these bodies are isolated segregations within the serpentine. The unaltered rocks of this type examined microscopically are all hornblende diorite or gabbro showing fine-grained textures varying in the same slide from "diabasic" to hypidiomorphic granular. The principal minerals are plagioclase, An 55-60, in euhedral to subhedral laths, and pale weakly pleochroic hornblende. In one slide the plagioclase is surrounded by rims of clear albite. Minor accessories include small amounts of skeletal ilmenite, sphene, and magnetite (?). Prehnite occurs in irregular veins, and in local areas within the rocks sometimes surrounding euhedral feldspar. Zoisite, chlorite, and saussurite are abundant alteration products. None of the specimens examined contain pyroxenes nor is there any other evidence to suggest that the amphiboles are secondary.

[25] Carey, E. P., and Miller, W. J., Crystalline rocks of the Oak Hills near San Jose: Jour. Geology, vol. 15, pp. 161-166, 1907.

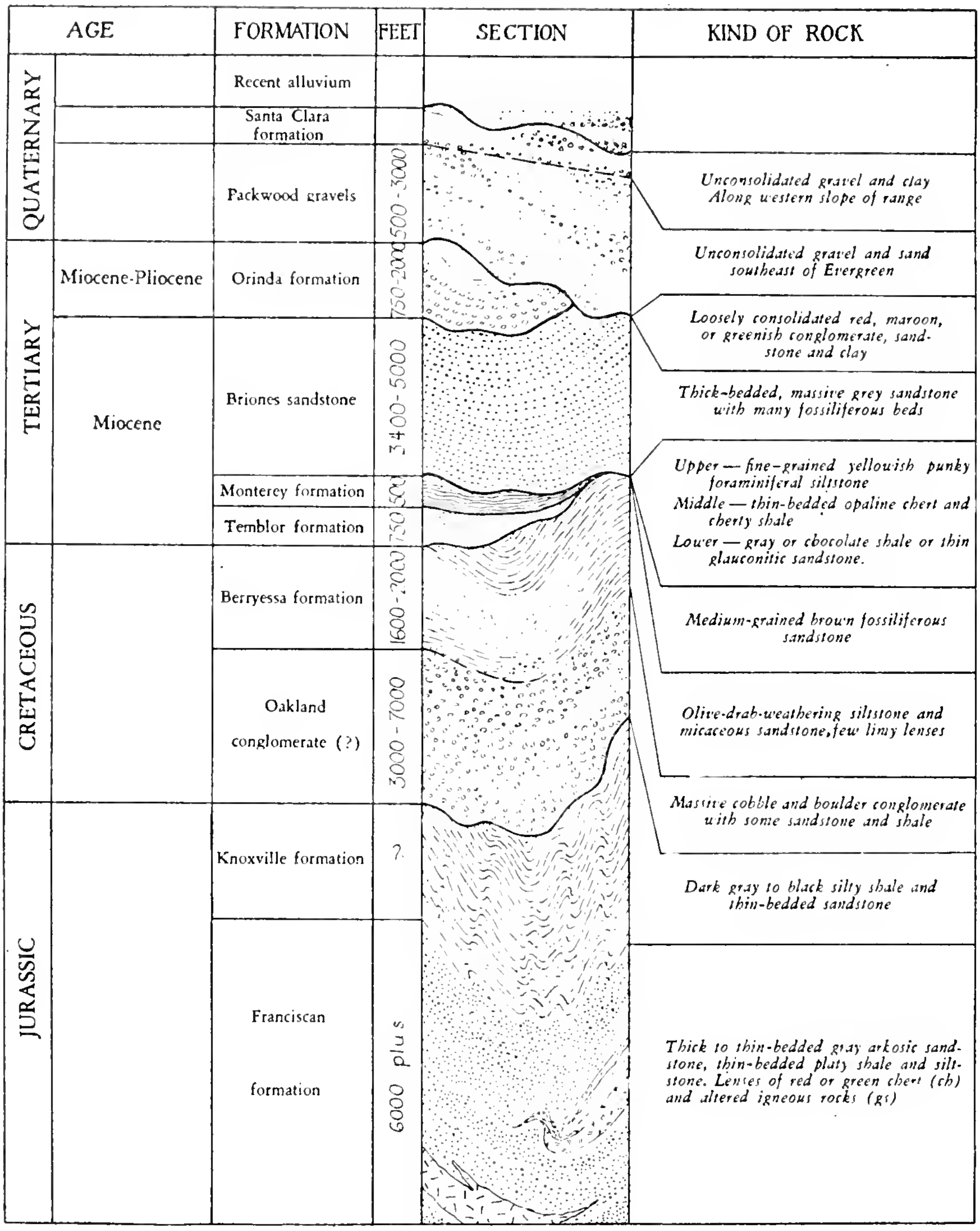

FIGURE 4. Generalized stratigraphic column of the San Jose-Mount Hamilton area

An unusual variety of hornblende gabbro crops out in an area of Franciscan rocks between Los Buellis Hills and Calaveras Creek. This body is a fine-grained to medium-grained hornblende gabbro at the core, but near the edge it becomes increasingly sheared and in places grades into fine-grained blue-gray mylonite. Under the microscope the mylonite shows incipient recrystallization to albite and fine-grained shreddy glaucophane. The occurrence is of special interest because of its intrusive relations to the Franciscan sediments, and its incipient metamorphism. At least two other occurrences of partly sheared gabbro have been reported in this area. One, in the bed of Calaveras Creek a short distance below Calaveras Dam, was described by Van Hise;[26] another, on Oak Ridge, was described by Smith.[27] Such an occurrence of sheared gabbro in which glaucophane was developing apparently led Van Hise to the conclusion that all the schists are of dynamothermal origin.

Alteration of Serpentine. Several different products seem to result from the alteration of serpentine by weak hydrothermal activity, all of which are distinct from the metamorphic rocks of the glaucophane schist facies which also may be produced at times from serpentine. In the area of Calaveras Dam, particularly near and below the high-water line west of the spillway, a pale gray-green lustrous rock is found which consists almost entirely of talc in interlocking plates up to several millimeters in diameter, and a few scattered grains of powdery magnetite. This rock grades laterally into ordinary sheared serpentine.

Another alteration product observed in this area, and in the large slide of lower Alum Rock Canyon, is a soft friable greenish-gray mass containing rounded white nodules of hydromagnesite. The nodules are half a centimeter to 4 centimeters in diameter and have a rather botryoidal surface. The mineral is soft and chalky and consists of a cryptocrystalline aggregate which cannot be resolved sufficiently to determine its detailed properties, even under high power. The refractive index and birefringence are within the range of hydromagnesite.

Alteration to magnesite-quartz rocks is not widespread, but does occur in the Oak Hills south of San Jose. The common massive porcelaneous variety of magnesite veined by quartz, occurs near the now abandoned San Juan quicksilver mine, and euhedral magnesite from this locality has been described by Rogers.[28]

Silica-Carbonate Rock. The most widespread product resulting from the alteration of serpentine is the distinctive and colorful silica-carbonate rock. This unusual and characteristic material occurs as lenticular masses or narrow bands along fault zones and around the borders of some bodies of serpentine. Its bold rugged outcrops consist of yellowish-brown ocherous masses whose texture is diverse. It is most commonly slaggy or cavernous, but much of it is gnarled, knotted, and brecciated. Weathered outcrops are heavily stained with limonite. The fresh rock, where found at some depth, usually consists of greenish- or brownish-white coarse-grained carbonates, commonly dolomite with some ankerite, veined by quartz, chalcedony, and, rarely, opal.

[26] Van Hise, C. R., Metamorphism of rocks and rock flowage: Geol. Soc. America Bull., vol. 9, p. 813, 1898.

[27] Smith, James Perrin, The paragenesis of the minerals in the glaucophane-bearing rocks of California: Am. Philos. Soc. Proc., vol. 45, pp. 207-209, 1907.

[28] Rogers, A. F., Euhedral magnesite crystals from San Jose, California: Am. Mineralogist, vol. 8, no. 8, pp. 138-140, 1923.

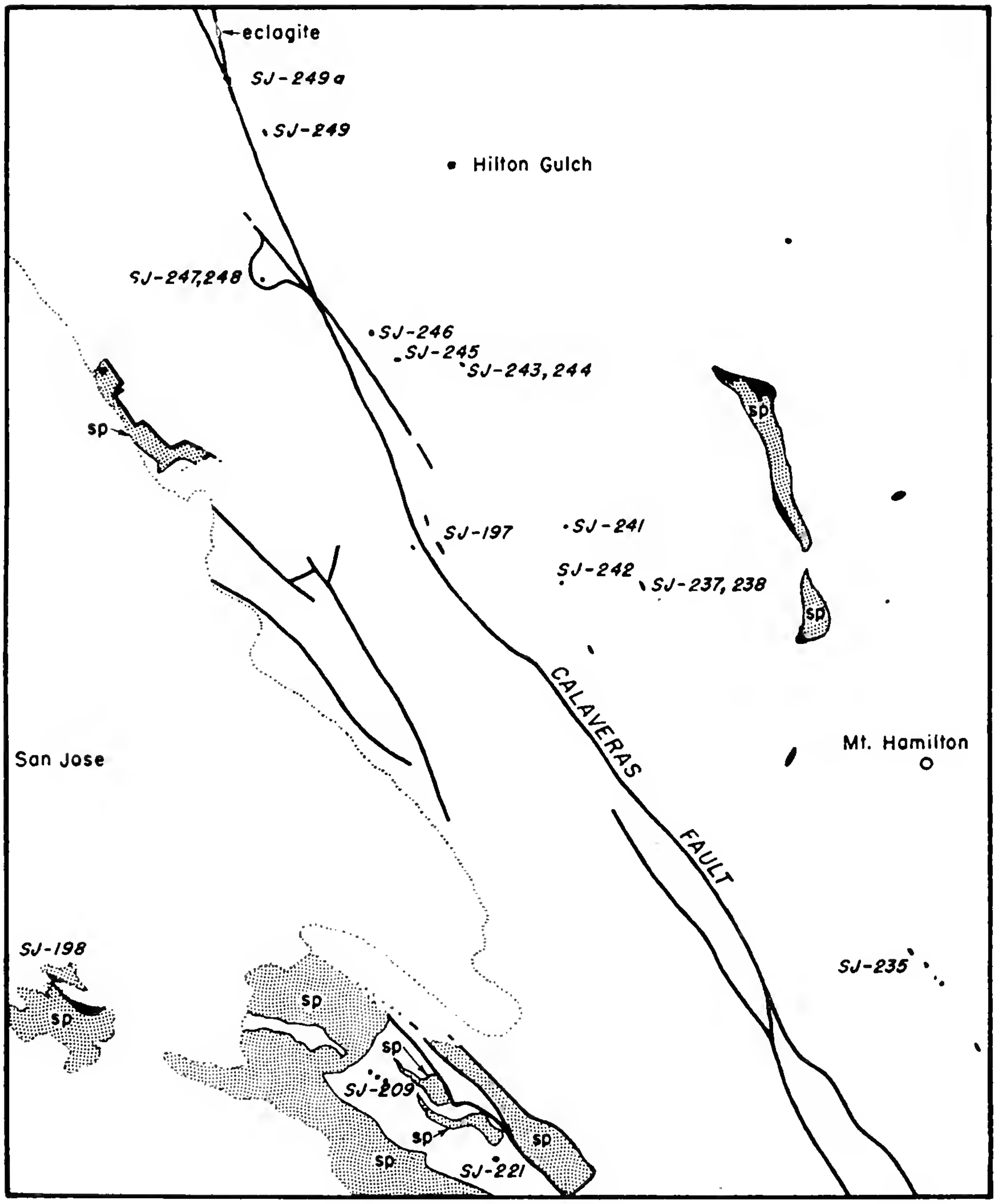

FIGURE 5. Distribution of glaucophane schist (black) and serpentine (sp) in the San Jose-Mount Hamilton area. Numbers refer to specimens

Small masses a few feet to a hundred feet in length occur along faults near the edge of the valley from the Silver Creek quicksilver mine to the mouth of Alum Rock Canyon, and somewhat larger masses occur along a fault which has localized the deposits at the Hillside mine in Oak Hill. The most extensive bodies are those at the boundary of the serpentine east of Edenvale, where the silica-carbonate rock occurs as a band or as interrupted lenses a few feet to a hundred feet thick extending for a distance of 3 miles along the contact. Throughout most of the distance it forms a prominent wall or rampart which stands as much as 25 feet above the surrounding serpentine and Franciscan sediments. Throughout its length, the silica-carbonate rock shows many textural and structural features of the serpentine from which it was derived; in fact, it grades into the serpentine on one side. In places it is cut by sharply defined quartz veins, whose orientation is remarkably uniform over a distance of several hundred feet, even where the band of silica-carbonate rock is sharply curved.

The development of silica-carbonate rock by hydrothermal alteration of serpentine is no longer questioned, and in the Coast Ranges its association with Tertiary or younger quicksilver deposits has led to the conclusion that the hydrothermal solutions are genetically related to Tertiary or Quaternary volcanism. It is seldom possible, however, to demonstrate their association with a particular igneous body but such an association does occur in the Alum Rock area east of San Jose where a plug of Alum Rock rhyolite has intruded shale and conglomerate of Cretaceous age. Although the wall rocks at the level now exposed are all of Cretaceous age, a thin discontinuous wrapping of serpentine has been carried up around the plug itself. Detailed examination reveals that this has been altered to silica-carbonate rock at several places along the contact with the rhyolite. This alteration and the still active thermal and chalybeate springs nearby, suggest strongly that the silica-carbonate rock here was formed by solutions which are genetically related to the Alum Rock rhyolite.

Franciscan Schists. The unusual and distinctive metamorphic rocks comprising the glaucophane schists are the most remarkable and characteristic feature of the Franciscan formation. The diversity of their form and occurrence, their unusual mineralogy, and the apparent anomalies among the mineral assemblages have stimulated widespread interest and study. At the outset, it should be understood that the term "glaucophane schist" is loosely used, and that it includes an assemblage of low-grade metamorphic rocks of diverse mineralogical and textural character, which may or may not contain glaucophane, and which may be massive rather than schistose.

A large number of the glaucophane schist bodies are small and isolated and show no visible connection with serpentine or ultrabasic rocks. They commonly crop out as rugged crags or large bouldery masses surrounded by smooth grassy areas in which outcrops are poor or lacking; only rarely can one observe a transition from schist to unaltered source rock.

The most extensive areas of glaucophane-bearing rocks in the San Jose-Mount Hamilton area are those associated with the long narrow serpentine sill northwest of Mount Hamilton. Here they occur as narrow lenses mostly along the western, presumably upper, margin of the sill, and as irregular areas interfingering with the serpentine and the sediments.

The large body at the north end of the sill is a coarse-grained rock of varied texture and composition. It includes chlorite, muscovite, talc, actinolite, and glaucophane schists, some of which were derived from Franciscan sediments, and some of which were formed from the serpentine itself. To the northwest, the intensity of metamorphism dies out, and the schists grade into sheared semischistose sediments. The transition is gradual here, and any placing of the contact necessarily arbitrary.

Glaucophane schists are also associated with serpentine near the mouth of Berryessa Creek, where a small rounded pillar-shaped body of chlorite-actinolite rock crops out in an area of soft sheared blue-green serpentine. The general pipe-like form of this mass and the composition suggest that it was formed by metasomatic alteration of the serpentine itself.

Another occurrence of schist on the border of a body of serpentine was noted in the Oak Hills, near the Hillsdale mine. A strikingly beautiful glaucophane-muscovite-quartz-albite-lawsonite schist has developed here from Franciscan chert.

The most unusual rocks of the glaucophane schists are the so-called eclogites which contain large euhedral garnets, green pyroxene, and rutile, and smaller amounts of glaucophane, actinolite, chlorite, muscovite, and sphene. Such rocks have been described from Hilton Gulch, a steep tributary to Arroyo Hondo, and from Calaveras Valley.[29]

The many small bodies of schist scattered through the Franciscan formation show a diversity of source rock including chert, sandstone, and gabbro. Many other rock types have been affected, but only these could be traced laterally into unaltered rock or could be identified by relict textures. In several places, the folded and crumpled bedding of this original rock is preserved, and can be traced through the schists.

The glaucophane schists of the San Jose-Mount Hamilton area are believed to have formed through metasomatic alteration of Franciscan sedimentary and igneous rocks (including serpentine, diorite, etc.) by solutions carrying sodium, calcium, magnesium, iron, alumina, and genetically connected, probably at depth, with ultrabasic rocks. The temperature and pressure conditions are believed to be those of the green schist facies. The eclogites and garnet amphibolites of this area all appear to be unstable under the conditions which led to the development of glaucophane and are believed to represent an earlier period and a higher grade of metamorphism. There is insufficient evidence to determine whether they were formed at depth and carried up by serpentine, or were formed in place during an early phase of the metasomatic process.

Knoxville (?) Formation

Distribution and Thickness. Rocks provisionally assigned to the Knoxville formation crop out in a relatively restricted area southeast of Evergreen. At the south edge of the map they extend from the Silver Creek fault to the Calaveras fault, apparently without interruption. The

[29] Holway, R. S., Eclogites in California: Jour. Geology, vol. 12, pp. 344-358, 1904.
Smith, J. P., op. cit.
Pabst, Adolf, The garnets in the glaucophane schists of California: Am. Mineralogist, vol. 16, no. 8, pp. 327-333, 1931.

western limit, as far as it is visible, appears to be a fault of the Silver Creek zone. To the north they are overlain by the Oakland conglomerate of Cretaceous age, whose base crosses the ridge west of San Felipe Valley and disappears beneath the alluvium east of Evergreen. The thickness of these rocks is unknown; it is impossible even to give a minimum value, or to recount a continuous section of any kind. This is due almost entirely to lack of knowledge of the structure, rather than lack of exposure, or faulting, or other factors. The lack of recognizable stratigraphic or lithologic units leaves no basis for even an estimate of the thickness.

Lithology and Structure. Thin-bedded dark-gray shale and siltstone are the predominant rocks in the area mapped as Knoxville. Some sandstone may be interbedded, and it may predominate locally. Thin lenticular limestone beds and concretions occur here and there, and are the source of many of the fossils discovered. These are black on fresh surfaces, but weather to light brown or gray. Conglomerate was found in several places, and it too was fossiliferous. The prevailing dark-colored siltstone, presumed to be characteristic of the Knoxville, is particularly evident along the lower part of San Felipe road, and along the steep slope west of Dry Creek. At many other places, however, the rocks are olive drab to light brown, and resemble greatly the rocks of the Berryessa formation. This is a natural variation, but may also be a result of weathering in more exposed areas. The sandstone is mostly thin bedded, grading into and interbedded with siltstone and shale. Coarse-grained massive sandstone is found locally, and may contain the wrinkled biotite which is so characteristic of the sandstone of the Berryessa formation. Shale flakes and wood fragments occur in both sandstone and conglomerate. Most of the conglomerate contains black chert, porphyry, and other materials of the Franciscan formation, but some also contains black limestone that is probably derived from the Knoxville itself.

The almost complete lack of information on structure within the Knoxville has already been pointed out. Some general features are evident, however. The general trend of the prevailing attitudes and their relation to the base of the younger Oakland conglomerate indicates that the Knoxville is crumpled and folded complexly. The numerous northeast strikes apparently delineate folds trending in that direction, and suggest the possibility of an unconformity between the Knoxville and younger rocks.

Andesite. A sill of pale cream, gray, or greenish altered andesite is enclosed in sandstone and shale of the Knoxville on the slope north of Dry Creek, southeast of the Richmond Ranch. Where it is exposed along the road it is only a few feet thick, and is so altered that it is scarcely recognizable. A short distance northwest, it thickens and becomes distinctly porphyritic. In thin section the rock is vaguely porphyritic, with a medium-grained pilotaxitic groundmass. What appear to be phenocrysts in the hand specimen are sharply outlined areas of chlorite and quartz or calcite pseudomorphous after hornblende (?). No feldspar phenocrysts are evident. The groundmass consists of slender laths of twinned labradorite about 0.2 of a millimeter long. It commonly shows zoning, with a continuous gradation from about An 70 in the interior to about An 50 in the rim. The interstices between the laths are filled with calcite and quartz; minute euhedral crystals, probably of magnetite, shreds of brown biotite, and a few grains of epidote are also present.

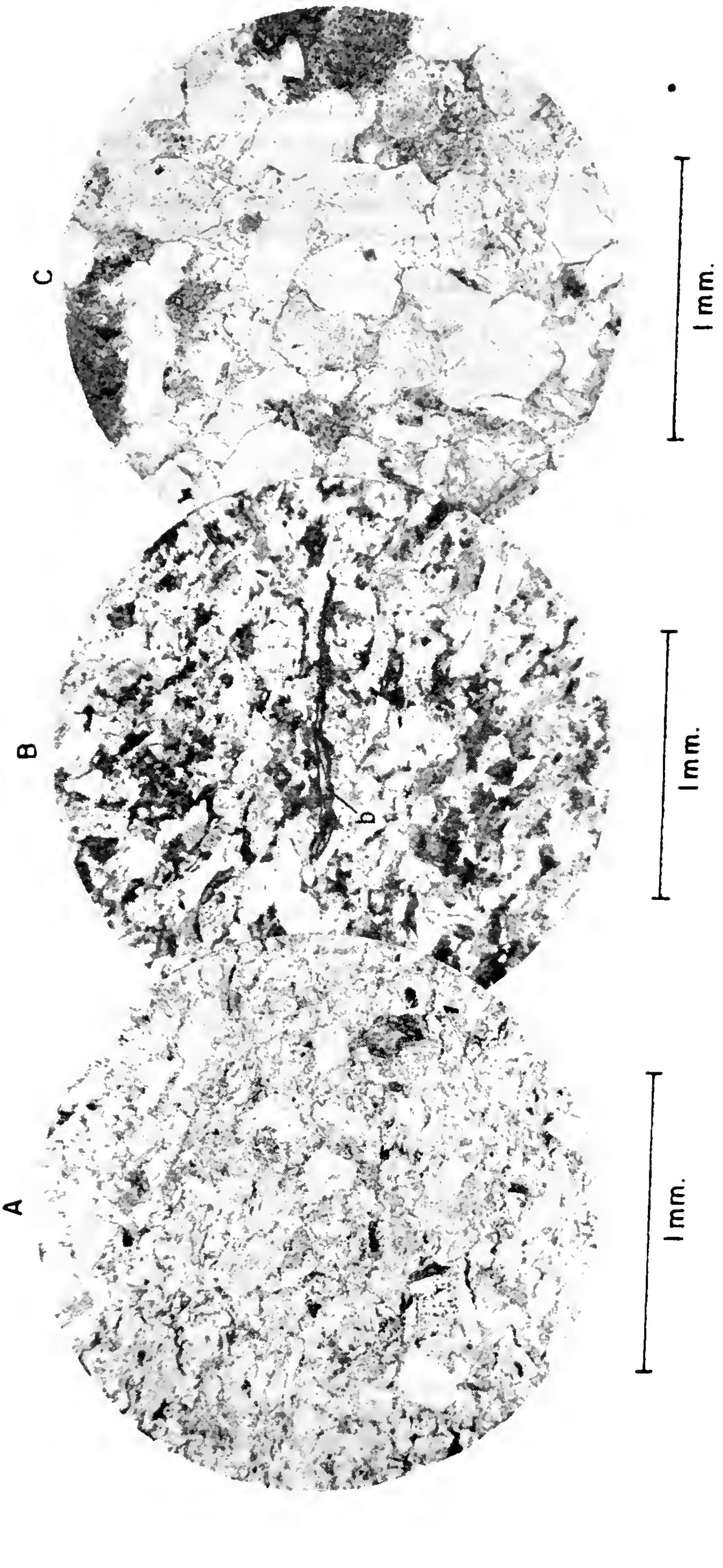

FIGURE 6. Photomicrographs of Franciscan (A), Berryessa (B), and Briones (C) sandstones. The Franciscan and Berryessa sandstones are impure and contain many rock fragments. The wavy plate of altered biotite is characteristic of the Berryessa sandstone (b)

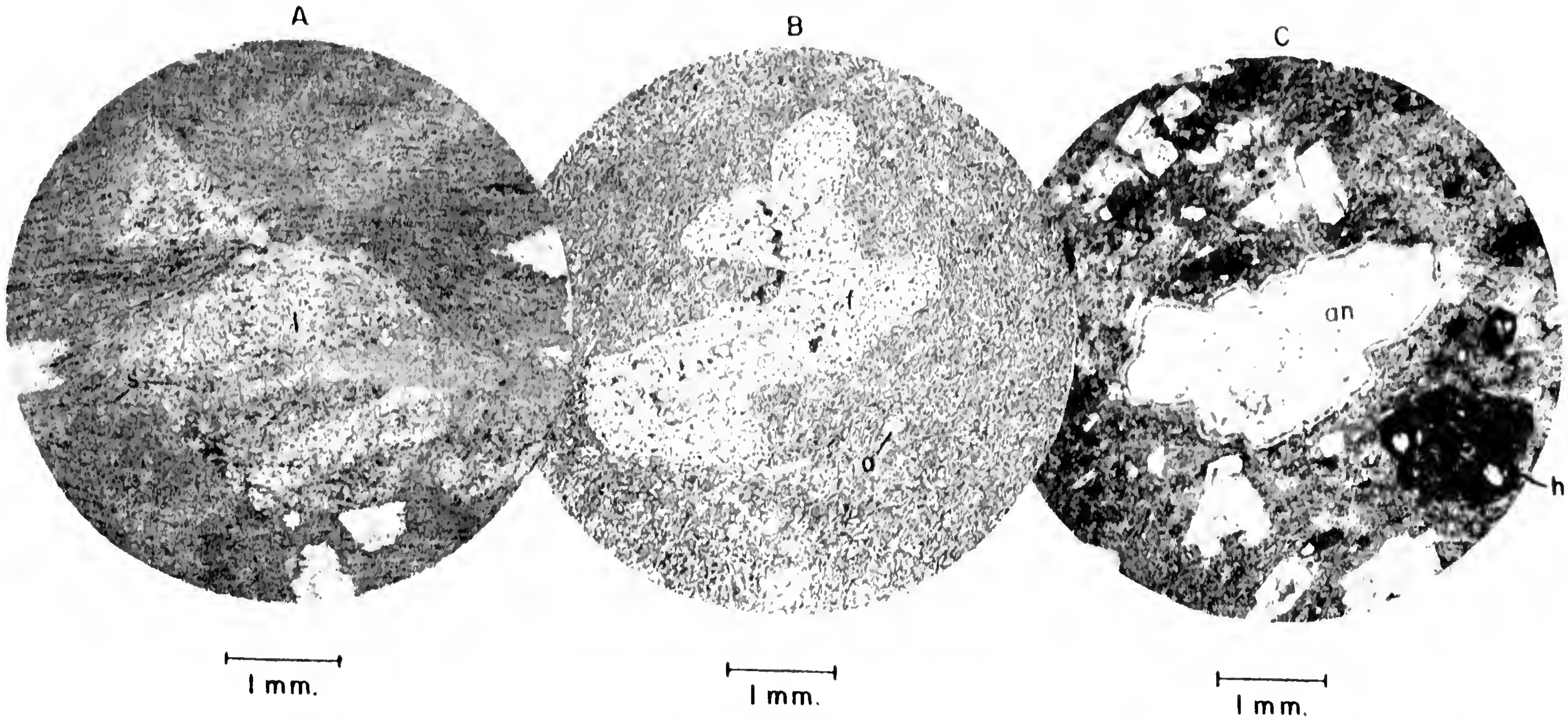

FIGURE 7. (A) Photomicrograph of lawsonite-glaucophane schist. Lawsonite porphyroblasts (l) in fine-grained glaucophane schist; note rows of sphene granules (s) passing through and around the lawsonite. (B) Photomicrograph of andesite from Silver Creek. Large phenocrysts of oligoclase-andesine (f) with "wormy" inclusions of glass. The groundmass contains microlites of plagioclase and augite (a) in a matrix of cloudy brown glass. (C) Photomicrograph of hornblende andesite from the Orinda formation. Phenocrysts of andesine (an) and oxidized hornblende (h) in a fine-grained groundmass of feldspar microlites and cloudy glass

Age and Relations to Adjoining Formations. The age and designation of the unit mapped as Knoxville is based on meager fossil evidence and general stratigraphic position, and as a result is uncertain and subject to modification by more detailed study. Moreover, the unit mapped may not be entirely homogenous; fossils have been found in only a small part of the area.

Buchias (Aucellas), a few belemnites, and an ammonite fragment were found within the San Jose-Mount Hamilton area, and a poorly preserved ammonite and a gastropod were found just south of the area mapped. These were identified as:

Buchia piochii (Gabb)
Belemnites sp.
Perisphinctes sp.
Turritella sp.

None of these is sufficiently restricted in range, or well enough preserved to define the age of the beds unequivocally. The status of the genus *Buchia* is particularly doubtful; but the occurrence of the narrow-beaked species (*piochii*) and the absence of the broad bulbous forms suggests an Upper Jurassic rather than a Lower Cretaceous age, in spite of the fact that the two types have been found together at many other places in the Coast Ranges. Unfortunately, the ammonites found here, and others in the collections of Stanford University, are too poorly preserved to be determined specifically.[30]

The base of this formation was not found within the area mapped, but may crop out in the north edge of the Morgan Hill quadrangle. The fault contact with serpentine west of Dry Creek is so designated because it appears from the mapping to dip southwest, and the shale adjoining appears to dip northeast and to diverge considerably in strike. No induration or baking of the shale was observed.

Throughout most of its length, the contact between the Knoxville and the overlying Oakland conglomerate is drawn on a purely lithologic basis, at the base of the lowest massive conglomerate; for most of the distance this is all that the exposures warrant. However, in one locality 0.85 of a mile N. 10° E. of the Richmond Ranch, a thin fossiliferous conglomerate crops out about 200 feet below the base of the massive Oakland conglomerate. This bed, containing only the broad *Buchia crassa,* and overlying the dark Knoxville shales, is believed to be the base of the Cretaceous. It was impossible to follow this horizon eastward, and it is likely that elsewhere along the contact beds of Cretaceous age may be included in the top of the unit mapped as Knoxville. Thus the Jurassic-Cretaceous time boundary probably falls near the top, but within the unit mapped as Knoxville, except at the one locality mentioned. This inconsistency in mapping and usage is unfortunate, particularly in view of the confusion that already exists concerning the use of the term Knoxville.

Cretaceous System

Overlying the dark shales of the Knoxville, and below the youngest rocks of the Monterey formation are two lithologic units of Cretaceous age. The lower unit is mostly coarse cobble and boulder conglomerate of variable thickness. The upper unit is mostly sandstone and thin-

[30] Muller, S. W., Oral communication.

bedded siltstone. Fossils are rare in both units, and the age designation depends in part on their stratigraphic position and lithologic similarity to rocks of Cretaceous age in adjoining areas.

The name Oakland conglomerate is applied to the lower unit of the Cretaceous system, following the usage of Lawson,[31] who mapped thick conglomerates of identical character in the Hayward and Concord quadrangles. From the type section at Oakland, the unit crops out continuously to Niles, in the Pleasanton quandrangle, only 6 miles northwest of the area mapped. The name as used by Lawson was actually the "Oakland conglomerate member" of the Chico formation. This designation is not adopted here because of the fossil evidence suggesting a Lower Cretaceous age and because the term "Chico" has been so broadly applied that it no longer has a reasonable stratigraphic significance. The lithologic identity of the thick conglomerates of the San Jose and Oakland areas seems sufficient to warrant the use of Lawson's term, whatever the stratigraphic significance may ultimately prove to be.

A new local name, Berryessa formation, is applied here to the upper unit of the Cretaceous in the San Jose-Mount Hamilton area. The Berryessa formation consists of micaceous sandstone and siltstone called Chico by Lawson,[32] and included in the Knoxville by Templeton.[33] The introduction of a new name for this formation does not imply that its exact age and stratigraphic position are known, but rather is an attempt to avoid the confusion associated with the name Chico, and to provide a simple name for this unit which eventually can be correlated with other sections when the information permits. Both the Oakland conglomerate and the Berryessa formation are Lower Cretaceous in part, and are included in the Shasta group by Taliaferro [34] in a section drawn through this area.

Oakland (?) Conglomerate

Distribution and Thickness. The largest exposures of the Oakland conglomerate are east and southeast of Evergreen, where it forms a broad band extending northwest across the range from San Felipe Valley to the edge of the Santa Clara Valley. It does not stop there, however, as indicated by two isolated hills of conglomerate which project through the alluvium northeast of Evergreen and by wells in the same area which encountered conglomerate within 500 feet of the surface. It crops out again in the low hills bordering the valley east of the cross roads labeled "Alum Rock" on plate 1. Another exposure crops out north of Mount Hamilton Road and extends northwest across lower Alum Rock Canyon as far as Berryessa Creek. For much of this distance, it is covered by landslides and the Santa Clara formation, so that its relationship to the serpentine against which it is faulted south of Berryessa Creek is obscured.

A single body of similar conglomerate is exposed in the pits and trenches at the north end of Calaveras Reservoir. This is included in the Oakland conglomerate with hesitation, and it may actually be an entirely unrelated conglomerate, though it is undoubtedly of Cretaceous age.

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[31] Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193) p. 8, 1914.

[32] Op. cit., p. 8, 1914.

[33] Op. cit., Geol. Soc. America.

[34] Taliaferro, N. L., Geologic history and structure of the Central Coast Ranges of California: California Div. Mines Bull. 118, pl. 11, p. 162, 1943.

The thickness appears to be variable, and the lack of visible bedding makes accurate measurements uncertain. In the one place, near the Kuhn Ranch southeast of Evergreen, where the base and top are exposed, it is estimated to be 2,700 feet. Southeast of there, the outcrop expands greatly, to nearly 7,000 feet. Such a thickness is not impossible, but the few dips obtained in the area suggest that there may be folding which would account for it, at least in part. Nowhere else are both the base and the top of the formation exposed.

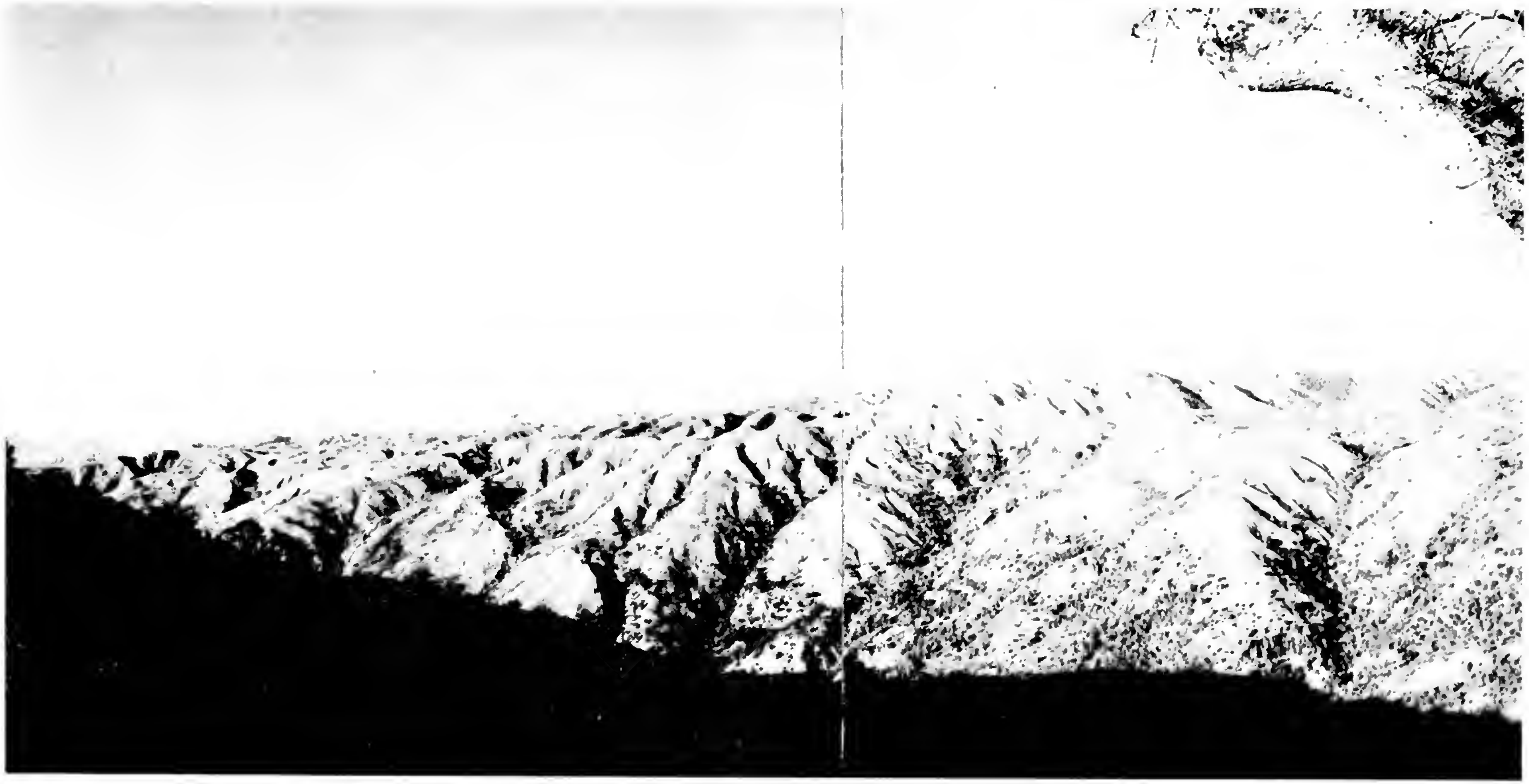
Lithology. The Oakland conglomerate commonly consists of subrounded to well-rounded cobbles with some boulders, in a matrix of coarse sand. It is generally massive, the bedding being very obscure or completely lacking. In large exposures, some faint imbrication of the pebbles is detectable, but most commonly their orientation is completely haphazard. The lithology is fairly uniform over large areas, pebbles consisting mostly of the same porphyries and quartzites found in the conglomerates of the Franciscan formation. A count of 82 pebbles was made in the cliffs at the mouth of Alum Rock Canyon, showing the following distribution of rock types:

Black chert	32
Porphyry (dark groundmass)	25
Black quartzite	11
Coarse-grained recrystallized sandstone	3
Gray limey shale	2
Dark-gray fine-grained limestone	2
Granitic rocks	1
Vesicular porphyry	1
Red chert	1
Vein quartz	1
Green porphyry	1
Aphanitic igneous rock	1

Age and Correlation. Fossils were reported from two localities in the massive conglomerate by Crandall.[35] Near the mouth of Berryessa Creek, *Aucella piochii* Gabb was found in both the pebbles and the matrix of the conglomerate. *Phylloceras knoxvillense* Stanton is also reported. In Alum Rock Canyon, Crandall reports *Belemnites* sp. and *Aucella piochii* Gabb from rocks now mapped as Oakland conglomerate. Recent search failed to disclose additional material from either of these localities, but *Aucella crassicolis* was found in a thin bed of pebbly sandstone enclosed in sandstone and shale in a new road-cut east of the San Jose Country Club. The beds may be Berryessa formation but are believed to be interbedded with the Oakland conglomerate.

One collection already mentioned in connection with the Knoxville (?) was found on the north slope of a small canyon 0.85 of a mile N. 10° E. of the house shown on the map (pl. 1) as the Richmond Ranch. The fossils are abundant, and occur in a bed of conglomeratic sandstone and in limestone concretions just below it. *Buchia crassa* is the only form identified. At least 50 feet of conglomerate resembling the Oakland conglomerate crops out just below the fossiliferous beds, but the base is not exposed. It is some distance to the nearest fossiliferous Knoxville shale. Two or three hundred feet of shale appear to intervene between the fossiliferous horizon and the main mass of the Oakland conglomerate.

[35] Crandall, Roderic, The Cretaceous statigraphy of the Santa Clara Valley: Am. Jour. Sci., 4th Ser., vol. 24, pp. 33-54, 1907.



GENTLY SLOPING SUMMIT OF OAK RIDGE
From summit of Poverty Ridge. Mount Diablo in background

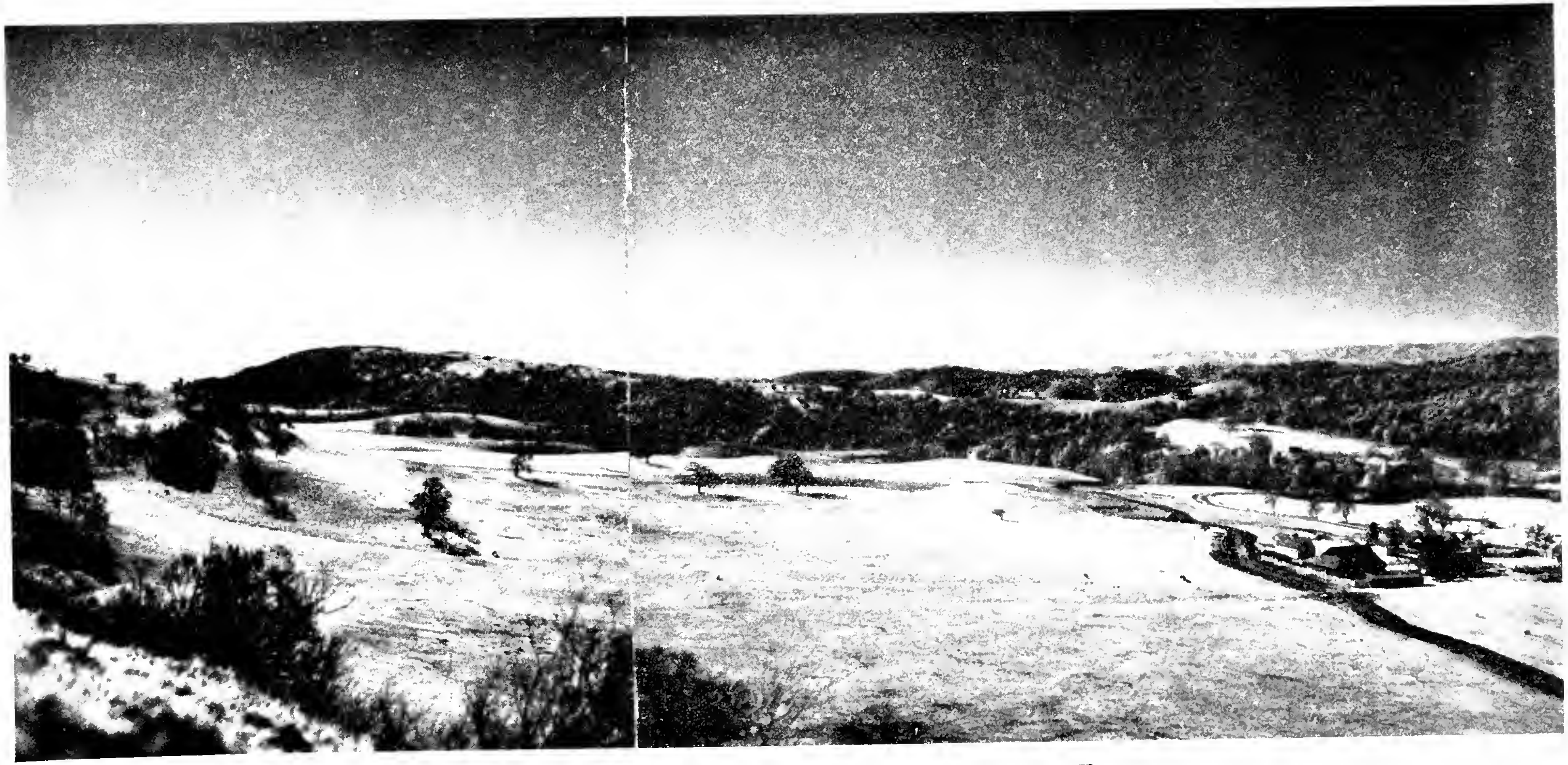
A, SUBDUED TOPOGRAPHY OF SAN FELIPE HILLS
Mount Hamilton and Lick Observatory in background

B, SMOOTH SUMMIT OF POVERTY RIDGE
View south from point on Poverty Ridge east of junction of Smith Creek and Isabel Creek

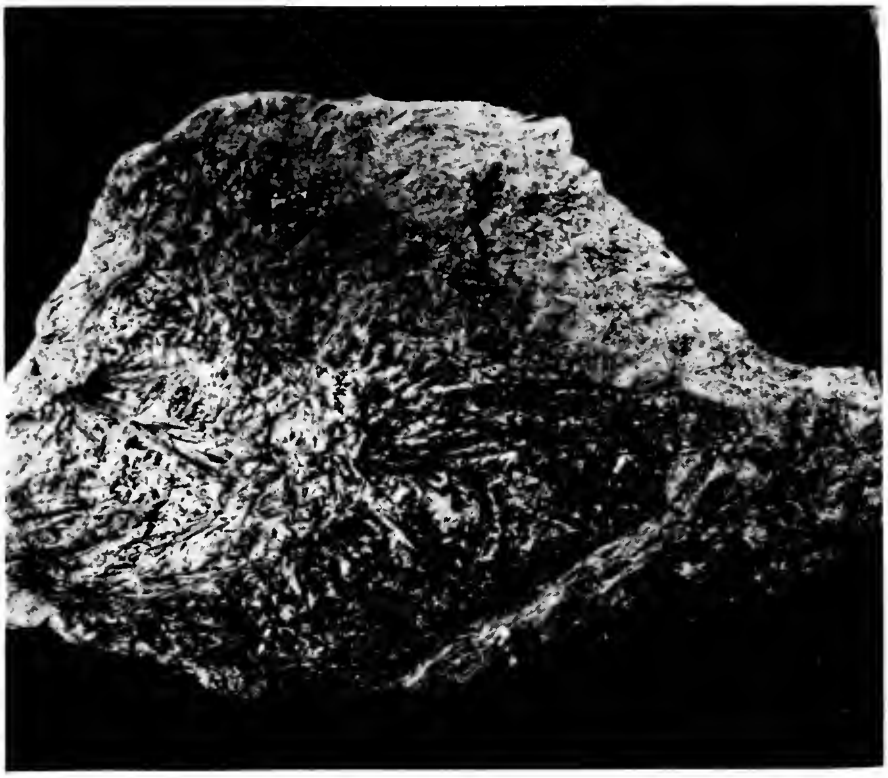
A, VIEW DOWN ARROYO HONDO
From point west of junction of Smith Creek and Isabel Creek.
Oak Ridge in rear, Poverty Ridge at left

B, SUBDUED TOPOGRAPHY
Of Los Buellis Hills and the north slopes of Alum Rock Canyon

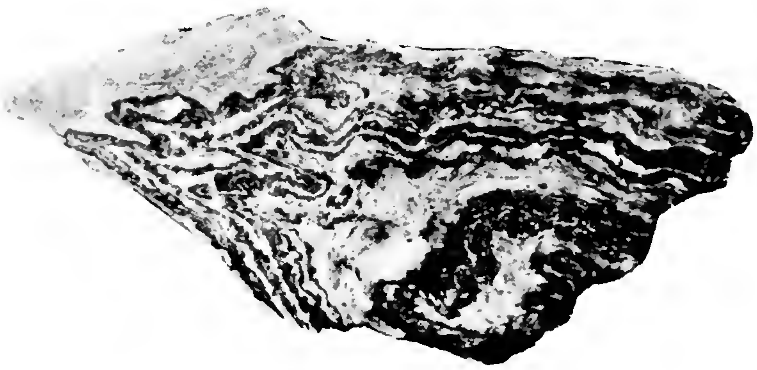
NORTH RIM OF ALUM ROCK CANYON, LOS BUELLIS HILLS
View north along the Calaveras fault zone from the Haskins triangulation station



VIEW SOUTHWEST ACROSS SAN FELIPE VALLEY
Tilted block in left center is being dissected from south by San Felipe Creek



A, NODULE OF BLADED ACTINOLITE AND TALC WRAPPED BY CHLORITE AND ACTINOLITE



B, CRUMPLED CHERT REPLACED BY GLAUCOPHANE SCHIST

OPALINE CHERT, MIDDLE MEMBER OF MONTEREY FORMATION
Just below Sulphur Springs, Alum Rock Park

BADLAND EROSION IN SANTA CLARA FORMATION
East of San Felipe Road

The fossil evidence cited above indicates a Lower Cretaceous age for the beds mapped as Oakland conglomerate in this area. The strike continuity and lithologic identity with the type locality of the formation and the lack of fossils at the type locality, suggest that the formation mapped by Lawson in Oakland may also be Lower Cretaceous. On this basis, the Oakland conglomerate is equivalent to parts of the Shasta group,[36] but the information available is not sufficient to define its range nor to indicate the stages to which it may be equivalent. In a section through the area, Taliaferro,[37] includes this unit in the Shasta group or undifferentiated Lower Cretaceous.

Berryessa Formation

Name, Occurence, and Thickness. The name Berryessa formation is introduced here to designate the sandstone, siltstone, and shale between the Lower Cretaceous Oakland conglomerate and the Tertiary Monterey formation. Berryessa Creek was chosen as the type locality because it is one of the few places where both the base and top of the formation are exposed, and because no faults of large displacement are known to cut the section. However, relations with the overlying Santa Clara formation suggest the possibility of minor faulting, and exposures are not complete enough to permit measurement of a detailed section.

Rocks assigned to the Berryessa formation crop out almost continuously along both sides of the Tularcitos syncline. One band extends along the Calaveras fault from the vicinity of Calaveras Reservoir to Halls Valley, except for a 1-mile break at the south end of Los Buellis Hills, and reappears for a short distance east of San Felipe Valley. The other band extends from Scott Creek across Alum Rock Canyon, then is faulted out for a distance of 3 miles except for one small patch. It reappears west of Masters Hill and extends southeast to Panochita Hill, faulted segments finally reaching the edge of the mapped area southeast of San Felipe Valley.

The thickness of the Berryessa formation is variable, and nowhere has it been determined with great accuracy. In the western limb of the Tularcitos syncline, it is about 1,000 feet thick at Berryessa Creek, about 1,600 feet thick at Alum Rock Canyon, and about 2,000 feet thick near the Hendricks Ranch. It may be considerably thicker south of there, but the base has not been mapped accurately, and the top is clearly faulted. At one place, about a mile south of Alum Rock Canyon, the Monterey formation overlaps the Berryessa formation completely.

Nowhere in the eastern limb of the Tularcitos syncline is a complete section of the Berryessa formation exposed. The only occurrence of a rock comparable with the Oakland conglomerate is separated from the rest of the section by obvious faults of the Calaveras system. Consequently, only a minimum thickness can be given, and it is difficult to be sure that structural complications are eliminated. The field mapping suggests that the small syncline shown on section A-A′ (pl. 2) dies out to the south, and it appears that at least 2,000 feet of sandstone, siltstone, and shale mapped as Berryessa formation crop out below the base of the Monterey formation.

[36] Taliaferro, N. L., The Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, pp. 109-219, 1943.
[37] Op. cit., Am. Assoc. Petroleum Geologists, pl. 2, section 9.

Lithology. The Berryessa formation includes siltstone and shale that weather to olive drab, thin-bedded micaceous sandstone, and particularly in the east limb of the Tularcitos syncline, massive, thick-bedded sandstone. Brown wrinkled biotite occurring in large conspicuous flakes in the sandstones and as fine particles throughout the siltstone and shale is a characteristic feature of most exposures. It is usually oriented parallel to the bedding and can be used to determine the attitude of small outcrops of massive sandstone. It is also of assistance in distinguishing these sandstones from sandstones of the Franciscan formation, which generally contain smooth pearly flakes of muscovite instead of the wrinkled biotite. Carbonized wood fragments and plant remains are abundant in many places, and may be quite large.

The fresh, massive sandstone from a deep cut on the road west of Calaveras Reservoir is a fine-grained rather poorly sorted arkose, containing many fragments of carbonized wood. The grains are mostly very angular, and there is a large amount of fine silty interstitial material. The cement is mostly a brown carbonate, which is probably ankerite or ferrian dolomite, since it appears in abundance in the heavy separate. Orientation of platy forms is quite marked. The most conspicuous are large altered biotite flakes, which no longer show the birefringence and absorption of biotite. Here and there, however, a thicker flake does show these properties. A grain count of the light minerals in this rock gave 20 percent quartz, 30 percent feldspar, 49 percent rock fragments and composite grains.

Age and Correlation. Only a few fossils have been found in the beds designated here as Berryessa formation, none of them during the present study. However, Crandall [38] reports fossils from several places northeast of Milpitas, the best exposures being in the lower port of Arroyo de los Coches. The forms listed are:

Aucella piochii Gabb
Hoplites (fragment)
Belemnites (fragment)
Pecten complixicosta Gabb

In Alum Rock Canyon, *Aucella piochii* and *Belemnites* are reported from a conglomerate, but the locality given by Templeton [39] is a quarter to half a mile west of the hotel, and much of this distance falls within the Berryessa formation. Crandall also reports *Aucella piochii* Gabb, *Aucella crassicollis Keyserling*, and *Venus varians* Gabb from several localities in Niles Canyon and from Mission Pass in the southern part of the Pleasanton quadrangle in beds which can be traced along the strike into the Berryessa formation.

Lacking more complete fossil evidence, the accurate correlation of the Berryessa formation is impossible. It is continuous along the strike with the Cretaceous shale and sandstone mapped by Harding,[40] and Erickson,[41] in the Pleasanton quadrangle, and by Lawson [42] in the Hayward quadrangle and the southwestern part of the Concord quadrangle.

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[38] Crandall, R., op. cit.
[39] Op. cit., Doctor's thesis, 1913.
[40] Harding, J. W., Geology of the southern part of the Pleasanton quadrangle, unpublished Master's thesis, University of California, Berkeley.
[41] Erickson, M. R., Geology of the western portion of the Pleasanton quadrangle, California, unpublished Master's thesis, University of California, Berkeley.
[42] Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193), 1914.

In all these areas, the rocks are mapped as "Chico". The fossil evidence summarized above, however, suggests that much of this so-called Chico is actually Lower Cretaceous, and should be correlated with the Shasta group, rather than the Chico group of northern California. This does not apply, of course, to the highly fossiliferous Chico beds mapped by Lawson in the Franklin anticline on the north edge of the Concord quadrangle, nor to the beds near Berkeley containing *Inoceramus* and *Baculites*. It is possible that the Berryessa formation may include some beds of Upper Cretaceous age, but the few fossils found so far do not indicate that this is the case. It should be pointed out that the rocks mapped as Berryessa formation in the western limb of the Tularcitos syncline may not all be the same age as those in the east limb near the Calaveras Reservoir. Moreover, there is the possibility that part of the beds mapped as Berryessa near the southeastern corner of the mapped area may actually be Eocene in age. Eocene shales, indistinguishable lithologically from the Cretaceous, have been mapped by Gilbert [43] in the northern part of the Morgan Hill quadrangle, and their northern limits are unknown.

Tertiary System

Tertiary rocks occupy much of the area between the Calaveras fault zone and the Santa Clara Valley, but the sequence of formations is relatively simple, and the range in age is limited. Although Eocene strata are known only a short distance south,[44] there is no evidence that they extend into the area mapped. If present, they are included in the Berryessa formation which they resemble closely.

The oldest lithologic unit known to be Tertiary is the middle (?) Miocene sandstone mapped as the Temblor formation. This unit is limited in extent to a small area north and east of Calaveras Dam, where it is overlain by a thin cherty shale mapped as Monterey. The Temblor is quite distinct both lithologically and faunally from the basal beds of the Monterey farther west. West of the Calaveras fault, the oldest rocks known to be Tertiary belong to the Monterey formation, and consist largely of opaline chert and thin-bedded shale overlain by fine-grained foraminiferal sandstone and siltstone. These strata are overlain with slight unconformity by the upper Miocene Briones sandstone which crops out as prominent reefs at many places in the area. The Miocene-Pliocene Orinda formation, dominantly maroon-red and greenish clays, silts, sandstones, and conglomerates, is the youngest unit mapped that is known to be Tertiary. The above formations all have been strongly folded, dip steeply, and are overturned at many places. They are separated from younger rocks by at least one episode of intense deformation, the Coast Range orogeny.[45]

Temblor Formation

Occurrence and Thickness. Fossiliferous Miocene rocks mapped as Temblor formation crop out in a small area north and east of Calaveras Reservoir where they rest unconformably on the Franciscan formation

[43] Gilbert, Charles M., Tertiary sediments northeast of Morgan Hill, California: Am. Assoc. Petroleum Geologists Bull., vol. 27, no. 5, p. 644, 1943.
[44] Gilbert, C. M., Tertiary sediments northeast of Morgan Hill, California: Am. Assoc. Petroleum Geologists Bull., vol. 27, no. 5, 1943.
[45] Taliaferro, N. L., The Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, no. 2, pp. 146, 156, 1943.

and grade upward into silicious Monterey shale. The formation crops out plainly in a fold trough on the point between the reservoir and Arroyo Hondo; it crops out again in a complexly faulted syncline on the ridge to the north, where it is overlain by both Monterey and Briones; it occurs again at the west end of the dam and in the prominent hill to the north. The nearly flat-lying contact of these beds with the underlying Franciscan is well exposed north of the quarry bench.

The Temblor formation is limited on the west by a fault of the Calaveras system which is exposed for less than a mile at the north edge of Calaveras Reservoir. The most recent movement on the fault was down on the east, causing the Temblor-Franciscan (serpentine) contact to dip into the Cretaceous. West of the fault, the Miocene has been considerably elevated, and the Temblor is absent.

The Temblor formation ranges from 500 to about 1,000 feet in thickness. A continuous section has not been measured; the thickest section and best exposures are near the spillway of Calaveras Dam, but the base is not exposed.

Lithology. The base of the Temblor formation is a conglomerate or conglomeratic sandstone several feet thick. The pebbles are well rounded, and average an inch or less in diameter, though large angular blocks of the underlying Franciscan occur at places. The most abundant pebbles are pre-Franciscan cherts, porphyries, and quartzites, but Franciscan chert and Monterey chert are also present. Fossils and especially fragments of fossils are very abundant; pectens and barnacles were recognized. Overlying the basal conglomerate are 50 to 100 feet of interbedded sandstone and pebbly sandstone, most of which is cross-bedded and filled with shell fragments. The greater part of the formation consists of fine-grained yellowish sandstone, commonly rather thick bedded. Fossils, especially pectens, are abundant throughout the section.

The occurrence of Monterey debris in the base of this formation stratigraphically below beds which are also mapped as Monterey [46] is worthy of special mention. Clearly, rocks with Monterey lithology were deposited over a considerable interval of time,[47] therefore the possibility of exposure and re-working does not seem unreasonable. In any case, however, it would indicate at least local uplift, within the period covered by the Monterey formation.

Age and Correlation. The age of the beds mapped as Temblor is made reasonably certain by even the small collection found during this work. The following were identified by J. W. Durham.

Bruclarkia oregonensis (Conrad)
Pecten propatulus Conrad
Chione sp.
Mytilus sp.
Cerastoderma sp.

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[46] Kleinpell, R. M., Miocene stratigraphy of California, fig. 14, Am. Assoc. Petroleum Geologists, 1938.

[47] Bramlette, M. N., The Monterey formation of California and the origin of the siliceous rocks: U. S. Geol. Survey Prof. Paper 212, pl. 2, 1946.

Monterey Formation

The term "Monterey formation" is here applied, following Bramlette[48] and Woodring[49] to the middle and possibly upper Miocene rocks characterized by an abundance of siliceous sediments. The fact that they do not include the same lithologic units mapped by Lawson[50] in the San Francisco folio has also prompted the use of this term rather than Lawson's "Monterey group."

Occurrence and Thickness. The strata of the Monterey formation crop out on both sides of the Tularcitos syncline throughout most of the area mapped. In the west limb, the Monterey emerges from beneath the Santa Clara formation southeast of Warm Springs and extends without interruption across Alum Rock Canyon. It is faulted off about a mile south of Alum Rock Canyon, but reappears for a short distance, dipping east at moderate angles, toward the axis of the syncline. Beginning near the mouth of Alum Rock Canyon and extending southeast for 4½ miles near the edge of the valley is a down-faulted block of Monterey which is nearly flat lying and may locally dip either east or west. An isolated outcrop probably related to this block occurs at the edge of the valley about 1¾ miles northeast of Evergreen.

Between the Hendricks Ranch and the south end of Halls Valley, an apparently normal band of Monterey, dipping about 40° NE., is interrupted by two faults along which it is dragged out for a distance of 5 miles. At the north, it is faulted up against the Briones on the west, and at the south, it is faulted down into the Cretaceous on both sides. The Monterey crops out again in the west limb of the syncline south of Panochita Hill, and southeast of San Felipe Valley.

In the east limb of the Tularcitos syncline, the Monterey is exposed from the north edge of the map to Los Buellis Hills, where it is overlapped by the Briones sandstone. On Sierra Road, it is faulted out along the Calaveras fault but reappears in Alum Rock Canyon and in Arroyo Aguague where, though poorly exposed, it forms a thin bed between the Briones and Berryessa formations. The Monterey was not recognized between the Arroyo Aguague and Halls Valley, where it is again faulted out by the Calaveras fault zone. At the south end of Halls Valley, and east of Panochita Hill, it appears as thin lenses faulted against Franciscan. It is last seen between two faults of the Calaveras system about three quarters of a mile south of the triangulation station "Bacon," east of San Felipe Valley.

The Monterey formation is thickest in Alum Rock Canyon and vicinity, but it is impossible even here to measure a continuous section. The best exposures are on the steep slopes of Alum Rock Canyon where the upper foraminiferal member was measured and found to be 350 to 400 feet thick. About 500 feet of the cherty middle member crops out below this, but the Monterey-Cretaceous contact is not exposed.

The Monterey exposed in the west limb of the Tularcitos syncline is somewhat thinner to the north of Alum Rock Canyon, averaging 500 to 600 feet between Arroyo de Los Coches and Calera Creek. It thins

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48 Bramlette, M. N., op. cit., p. 3.

49 Woodring, W. P., Stewart, R., and Richards, R. W., Geology of the Kettleman Hills oilfield, California: U. S. Geol. Survey Prof. Paper 195, pp. 117-118, 1940.

50 Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193), 1914.

abruptly just south of Alum Rock Canyon, but this may be partly the result of faulting. The Monterey is decidedly thinner everywhere in the east limb of the syncline, ranging from a thin film to about 350 feet, but averaging less than 100 feet. East of the Calaveras fault, the Monterey is only about 350 feet thick.

Lithology. Three distinct lithologic units can be distinguished in the Monterey formation west of the Calaveras fault. Beginning at the base, these are: (1) a few feet of light gray to brown sandstone, more or less glauconitic, which may grade into gray or chocolate-colored shale; (2) thin-bedded opaline chert with very thin shale partings, usually a few hundred feet thick; (3) pale buff foraminiferal siltstone with some platy sandstone and massive silty sandstone. The lower sandstone unit has been observed in only a few places, where exposures are unusally good. The typical Monterey chert of the middle member in general crops out well, and can be recognized readily by float where it does not actually crop out. The upper member is rather soft, and crops out well in places, but not at all elsewhere.

In all the work done in this area since 1946, these three divisions have been recognized, and the Monterey-Briones contact has been drawn above the foraminiferal silts. However, in the work done before the war, this unit was included in the Briones at places, as along the lower part of the Mount Hamilton Road. This inconsistency is most unfortunate, but time has not permitted remapping the contact.

The basal sandstone of the Monterey is best exposed along the road in Arroyo de Los Coches, about 100 feet west of the bridge leading to the ranch house and quarry in the Monterey. Here, shale of the Berryessa is overlain by medium- to coarse-grained white sandstone containing glauconite in at least two beds. The sandstone grades upward into silty shale which in turn grades into thin-bedded chert. The transition to the upper member of the formation is gradual, and occurs within the quarry on the south side of the canyon. Glauconite-bearing sandstone, probably from the same horizon, was found in fresh road cuts near the line of section C-C′ (pl. 2), just south of the mouth of Alum Rock Canyon. The base of the Monterey is not exposed higher in Alum Rock Canyon, but gray to chocolate-colored shale underlying the Monterey chert is exposed in the lowest switchback of the road to the upper canyon.

The middle member of the Monterey formation is well exposed around the sulfur and soda springs in Alum Rock Park. It consists of rhythmically bedded pale cream-colored opaline chert and cherty shale characteristic of the Monterey formation throughout the Coast Ranges.[51] The bands of chert are from one inch to several inches thick, and most of them show some thin banding within each bed. The individual chert beds are separated by partings of shale an eighth to a quarter of an inch thick. Irregular beds and lenses of dense limestone are common near the base and the top of this member, and weather out as distinctive yellow ocherous masses. The cherty part of the Monterey shows strong local crumpling and may be intricately folded, even though the beds above and below show only broad, open folds.

The thin-bedded cherts grade upward into the shale, siltstone, and fine-grained sandstone of the upper member, which is best exposed on the north rim of Alum Rock Canyon. When fresh, the rocks are dark

[51] Bramlette, M. N., op. cit.

gray and massive; but in weathering, the massive beds commonly disintegrate, yielding soft punky or sandy debris. Foraminifera are abundant in many parts of the member, and are readily visible in many specimens. A few small pelecypods found in these beds were identified by J. W. Durham as *Lucina acutilineata* Conrad.

Age and Correlation. The age of the lowest beds of the Monterey formation of the Tularcitos syncline has not been determined. Neither megafossils nor foraminifera were found in the thin glauconitic sandstone at the base. Though foraminifera are very abundant in the upper member, they are poorly preserved, and the following were identified by R. M. Kleinpell in a rather small collection from this member.

Bolivina aff. marginata Cushman	rare
Bolivina aff. tumida Cushman	rare
Nonion costiferum (Cushman)	few
Nonionella miocenica (?) Cushman	rare
Virgulina californiensis Cushman	abundant

This assemblage is regarded by Kleinpell [52] as "not higher than uppermost Luisian. In this area, this would indicate a correlation with the bulk of the upper Claremont or the lower Tice at San Pablo. It is definitely older than the bulk of the Tice." On the basis of this data, it is probable that the Monterey formation as mapped in this area falls within the upper middle Miocene.

Briones Sandstone

Occurrence and Thickness. The Briones sandstone [53] is here applied to a thick series of massive coarse-grained fossiliferous sandstones and sandy shales which unconformably overlie the Monterey formation. The unit crops out almost without interruption for the entire length of the Tularcitos syncline. Throughout the west limb it rests on the Monterey formation, but in the east limb it rests for considerable distances on the Cretaceous Berryessa formation.

The Briones sandstone varies considerably in thickness. It is 1,650 feet thick near Calera Creek southeast of Warm Springs, 3,400 feet thick in Alum Rock Canyon, and about 3,500 feet thick on Felter Road at the north end of Los Buellis Hills. South of section D-D′ (pl. 2) the thickness is unknown because no younger beds are present. Along the line of section A-A′ (pl. 2), the formation thickens rapidly eastward to 5,000 feet.

Lithology. The Briones sandstone forms the most conspicuous and distinctive outcrops of any of the Tertiary formations. These are particularly evident on Monument Peak and the Los Buellis Hills where the steeply dipping beds crop out as narrow "reefs" which resemble rock walls or fences running straight over hills and valleys. Most of these reefs are massive sandstone beds 1 foot to 6 feet thick filled with shells and shell fragments and thoroughly cemented by calcium carbonate. Between the reefs, the hills are grassy and relatively smooth, and are underlain by less well cemented parts of the formation.

The sandstone of the Briones is dominantly massive, thick-bedded, medium- to coarse-grained, light colored when fresh, gray or buff when weathered. Plant and wood fragments are abundant in certain beds.

[52] Oral communication, 1945.
[53] Lawson, A. C., op. cit. 1914.

Cross-bedding is well developed locally and is particularly well exposed on the smooth worn outcrops in the bed of Penitencia Creek in upper Alum Rock Canyon. Conglomeratic layers noted at several places near the middle of the formation contain many pebbles and cobbles of yellowish limestone from the Monterey formation, large fragments of oyster shells, and more rarely some banded Monterey chert and pre-Franciscan porphyry. Interbedded with the massive, well-cemented sandstones are beds of friable siltstone and fine-grained sandstone. The typical fresh, massive Briones sandstone is a medium-grained, well-sorted arkosic sandstone cemented by carbonate.

Table 2. Mineral Analysis of Typical Briones Sandstone

	Percent
Light minerals	
Quartz	25
Feldspar	28
Carbonate	10
Rock fragments and composite grains	37
	100
Heavy minerals	
Green hornblende	49
Brown hornblende	11
Leucoxene	9
Magnetite-ilmenite	6
Apatite	5
Hematite?	4
Sphene	3
Zoisite	3
Garnet	3
Carbonate	2
Zircon	1
Chlorite	1
Tourmaline	<1
Glaucophane	<1
Rutile	present
	99

Age and Correlation. Although fossils are extremely abundant in parts of the Briones, only a few poor specimens were obtained by breaking the massive sandstones. These include:

Tivela merriami Trask (?)
Spisula selbyensis Packard (?)
Pecten propatulus Conrad

Large faunas from this area and adjoining parts of the Pleasanton quadrangle are listed by Templeton and Trask,[54] and the status of the unit was summarized in detail by Trask after study of collections at both the University of California and at Leland Stanford Jr. University. He concludes that the Briones is upper Miocene, and is more closely related to the overlying San Pablo group than to the underlying Monterey. This conclusion is borne out by recent work. The progressive overlap of the upper members of the Monterey group by the Briones in the southern part of the Pleasanton quadrangle, [55] and its ultimate overlap

[54] Trask, P. D., The Briones formation of middle California: Univ. California, Dept. Geol. Sci. Bull., vol. 13, no. 5, pp. 133-174, 1922.
Templeton, E. C., The geology and stratigraphy of the San Jose quadrangle, unpublished Doctor's thesis, Stanford Univ., 1913.
[55] Harding, J. W., op. cit.

onto the Cretaceous in the San Jose-Mount Hamilton area, give ample evidence of the persistent unconformity between the two. Worn pebbles of Monterey which appear in the middle of the Briones further emphasize the degree of uplift and erosion involved.

Orinda Formation

Occurrence and Thickness. Beds mapped as the Orinda formation are exposed in the center of the Tularcitos syncline from just south of the line of section D-D′ (pl. 2) to the north edge of the map. They are tightly folded, overturned in part, and rest unconformably on the Briones. Near the north edge of the quadrangle, the Orinda is about 2,000 feet thick. In sections C-C′ and D-D′, the thickness is estimated at about 750 feet. Near the Mountain House on the Mount Hamilton Road, only a hundred feet or so is exposed.

Lithology. The Orinda formation consists of red, maroon, green, or gray conglomerate, conglomeratic sandstone, silt, and clay. The conglomerates are most abundant on the west slopes of Monument Peak near the northwest corner of the area mapped, where they are commonly rather well cemented and crop out as broad ledges. In Arroyo de Los Coches, recent excavations have exposed a large area of maroon siltstone and mudstone with some greenish streaks. On Sierra Road maroon and greenish pebble and cobble conglomerate interbedded with pebbly sandstone crop out east of the highest Briones, and grade into silty and clayey beds farther east. The conglomerates are stained by manganese oxide, and are cut by many sheared surfaces. Recent excavations on the point between Arroyo Aguague and upper Alum Rock Road have exposed maroon and greenish clay in a narrow zone in a sharply folded and faulted part of the Tularcitos syncline.

The southernmost exposures of the Orinda formation are in a sharply overturned fold along the line of section D-D′ (pl. 2). Maroon and bright-red silt and clay streaked by green crop out in several places. These exposures are unusual in that they contain interbedded volcanics which are absent elsewhere in the area. Hornblende andesite lapilli tuff, and tuffaceous sandstone are interbedded with the usual sediments.

A single slide of hornblende andesite was examined under the microscope. It is a pinkish-gray rock containing phenocrysts of feldspar and pseudomorphs after hornblende. The feldspar phenocrysts are rather broad laths ranging in size from half a millimeter to 3 millimeters. They are complexly twinned, and most of them show oscillatory zoning throughout. The composition ranges from An 48 to An 57. The hornblende phenocrysts are narrow euhedral laths as much as 2 millimeters in length, which are entirely replaced by magnetite and hematite. The groundmass consists of microlites of basic feldspar in a matrix of cloudy glass with a refractive index greater than that of canada balsam. Hematite occurs in fine-grained plates throughout the groundmass; a few grains of quartz also occur. The most conspicuous minor accessory is an unusual brown pleochroic apatite, which occurs as euhedral crystals. The pleochroism is X—medium to dark brown, Y and Z—pale straw yellow. The refractive index was determined as $E=1.634$, $w=1.638$. Its identity was confirmed by F. J. Turner, by measuring the interfacial angles on the universal stage.

Age and Correlation. The correlation of the beds mapped in the San Jose-Mount Hamilton area with the Orinda formation [56] is based on lithologic similarity and stratigraphic position. From the type locality at Orinda, the formation extends southeastward through the Concord and Hayward quadrangles; [57] it was mapped by Erickson [58] to its intersection with the Sunol-Calaveras fault at Dublin. It appears again 12 miles south in the Tularcitos syncline near Mission San Jose, and is continuous from that point through the area mapped in the San Jose quadrangle. The age of the type Orinda formation was recently discussed by Durham,[59] and shown to be "in part at least as old as Neroly," and possibly "in part still older." Recent discoveries reported by Savage [60] indicate that the Orinda as mapped by Lawson includes beds as young as Blancan (Pliocene). The stratigraphic range of the Orinda in the San Jose area is unknown, and it can only be tentatively designated as Mio-Pliocene in age.

The Orinda formation overlies the Briones sandstone with slight angular unconformity. A discordance in dip of as much as 30 degrees appears at places. The Orinda is the youngest formation exposed in the Tularcitos syncline.

Tertiary-Quaternary (?) System

The rocks tenatively regarded as transitional between the Pliocene and the Pleistocene crop out beneath younger sediments around the margins of the present basins. In general, they have been tilted and involved in recent faulting, but they are clearly separated both spatially and structurally from the youngest folded rocks.

Where first studied, two units, the relatively consolidated Packwood gravels occurring between faults on Silver Creek, and the Santa Clara formation occurring on the slope east of San Jose, were regarded as belonging to this system. However, recent study of an extensive fauna from the Santa Clara formation at Irvington,[61] indicates that it is definitely Pleistocene in age. The Packwood gravels are not contiguous areally, and may be older than Pleistocene.

Packwood Gravels

The term Packwood gravels was applied by Tolman [62] to a series of unconsolidated sediments which crop out in the lower part of Packwood Creek, in the Morgan Hill quadrangle, where they occur in a block which has been dropped down between the Silver Creek and the Calaveras fault zones. To the north, they are bounded by a fault which leaves the Calaveras fault and swings northwest to joint the Silver Creek fault at the extreme south edge of the San Jose quadrangle. The formation reappears about a mile north along the Silver Creek fault zone, where it is dropped down between two faults.

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[56] Lawson, A. C., and Palache, C., The Berkeley Hills, a detail of Coast Range geology: Univ. California, Dept. Geol. Sci. Bull., vol. 2, pp. 349-350, 1902.

[57] Lawson, A. C., op. cit., 1914.

[58] Erickson, M. R., op. cit.

[59] Durham, J. W., Relationship of California upper Miocene-lower Pliocene vertebrate and invertebrate faunas (abstract): Geol. Soc. America Bull., vol. 57, no. 12, pl. 2, p. 1386, 1948.

[60] Savage, D. E., Blancan horse from near Walnut Creek, California: Geol. Soc. America Bull., vol. 59, no. 12, 1948.

[61] Savage, D. E., Late Cenozoic vertebrates of the San Francisco Bay region, in press, University of California, 1950.

[62] Op. cit.

In the type locality the formation consists of poorly consolidated gravel, pebbly sandstone, silt, and clay. Where it is best exposed along section E-E′ (pl. 2), it is well consolidated, and contains considerable white limy cement. It includes medium-grained cross-bedded sandstone and sandy conglomerate. Some of the pebbles are several inches in diameter. The most common rock types are pale ivory Monterey chert, Franciscan chert and sandstone, porphyries probably derived from the Oakland (?) conglomerate, and sandstone from the Berryessa formation. Near the west edge of the embayment of Packwood gravel just north of the line of section E-E′ (pl. 2) coarse boulders of diorite weathered from serpentine are very abundant, and suggest a very local source for this part of the formation.

The 500-foot thickness of Packwood gravel shown on section E-E′ (pl. 2) is arbitrary, and certainly is a minimum value. In the Morgan Hill quadrangle, where the outcrop is widest, the Packwood is exposed across the strike for about 2 miles. Reconnaissance indicates a homoclinal dip to the east of 10 to 30 degrees, yielding a thickness of at least 3,000 feet with neither base nor top exposed.

The lack of fossils in the Packwood gravels makes it impossible to date them or to correlate them accurately. It is possible that they are the equivalent in age of the Santa Clara formation mapped farther north, but their structural setting suggests that they are somewhat older. The magnitude of the faulting and the incipient folding they have undergone suggest possible correlation with Plio-Pleistocene deposits such as the Paso Robles and Paicines formations.

Quaternary System

Santa Clara Formation

Distribution and Facies. Unconsolidated sediments of the Santa Clara formation crop out almost continuously along the east edge of the Santa Clara Valley from Warm Springs south to Alum Rock Canyon. Smaller patches of similar character crop out east of Evergreen. South of Evergreen is a large area mapped as part of the Santa Clara formation, but whose identity with it is questionable.

From Warm Springs to Alum Rock Canyon, the formation shows reasonably constant character. Where exposed in recent cuts, it is obscurely bedded, poorly sorted, pebbly sandstone, siltstone, or clay. The strike of the beds throughout this distance is relatively constant, N. 30-40° W.; the dip ranges from 10° to 30° E. The formation is incoherent and has been so affected by sliding that little of the original bedding is visible in natural exposures. In fact, from Arroyo de Los Coches to Alum Rock Canyon, the outcrops of the formation are virtually outlined by the features of multiple and continued sliding.

In the small creeks immediately south of Arroyo de Los Coches, deep narrow gullies have been cut through such slide material. The walls show contorted and chaotic conglomerate, pebbly sandstone, and silt. Massive reddish bouldery clay, sticky and plastic in winter, shrunken and cracked in the summer, occurs everywhere. Curving slickensided surfaces cut all the material, no matter how incoherent. The area mapped as Santa Clara formation near the Hendricks Ranch northeast of Evergreen is a jumbled slide containing large amounts of angular fragments of Monterey, some fragments of the Berryessa formation, and much fine debris.

The small area of Santa Clara formation near the Kuhn Ranch consists of poorly sorted, loosely consolidated reddish and yellowish gravel, sand, and clay. The material is much coarser than average; it is chiefly cobbles and gravel from the Oakland conglomerate.

The large area of gravels extending from Evergreen to Dry Creek is included in the Santa Clara formation because it shows a gentle tilt to the east and crops out above, and is being overlapped by the younger alluvium. It is well exposed just east of San Felipe road, where small areas of badland erosion have formed in the steep banks. The gullying is developed in yellowish and reddish poorly consolidated sand and sandy gravel. Most of the debris is subrounded to subangular shale and sandstone from the Berryessa formation. The bedding strikes N. 60° W., and dips 30° NE. The difference in lithology and the lack of consolidation are largely responsible for the separation of these gravels from the area of gravel on Silver Creek mapped as Packwood.

Farther northwest, and immediately south of Evergreen, the hills are rolling, and are shown by wells to consist of gravel and clay. The few outcrops are apparently the tops of buried hills just being exhumed. Most of these are ordinary silica-carbonate rocks or serpentine. There is one unusual occurrence, however, 1.75 miles S. 27½° E. of Evergreen, where the rocky knoll consists not of altered serpentine, but of pebbly clay or silt, cemented and veined by coarse, bladed dolomite. It has the same yellow ocherous color and appearance as typical silica-carbonate rock, but contains rounded to angular pebbles and fragments of sandstone, shale, tuff, and limestone. This leaves little doubt that solutions capable of producing silica-carbonate rock were in action after the deposition of this part of the Santa Clara formation.

Age and Correlation. The Santa Clara formation has generally been regarded as Plio-Pleistocene, but no diagnostic or abundant evidence of its age was found in the San Jose area. Recently, a large vertebrate fauna was discovered in a northward extension of the formation near Irvington; this has been designated lower Pleistocene. On the basis of these recent discoveries, this part of the Santa Clara formation is considered equivalent to the upper part of the San Benito gravels,[63] and possibly to parts of the Paso Robles formation of the Salinas Valley. It apparently is younger than intensely folded Pliocene beds exposed near Concord.

Terrace Gravel

Deposits of coarse alluvium which have been tilted or warped, and which clearly are older than the present streams, appear in at least two places along the Calaveras fault zone. The most extensive deposits crop out in steep, gullied cliffs at the south end of the Calaveras Reservoir. They consist of poorly sorted gravel, clay, and cobbles dipping about 30° E. Exposures to the east indicate that deposition was on an irregular surface, probably much like that found now, but with less relief. There is very little suggestion of terrace development east of the Calaveras fault, but west of the fault there is a prominent bench which slopes gently northward; this has been deeply dissected by the present streams. It is developed on coarse unconsolidated cobble gravel and some silty sand;

[63] Wilson, Ivan F., Geology of the San Benito quadrangle, California: California Jour. Mines and Geology, vol. 39, pp. 183-270, 1943.

the dip is about 20° W. The cobbles are mostly subangular fragments of Franciscan sandstone.

The other occurrence of terrace gravel is in the south end of the San Felipe Valley. Here a well-developed series of gravels and sands which dip gently northward are being dissected by San Felipe Creek. Their present surface is accordant with the long smooth slope to the south. It suggests a reversal of drainage in this area, which is well supported by physiographic evidence. The gravel here is subangular, and is mostly from the Berryessa formation.

Landslides

Landslides of sufficient size have been mapped wherever practicable; however, there are many which have been omitted, particularly where it is difficult to distinguish them from the underlying rock. Large areas of the Santa Clara formation have undergone repeated sliding, but it is almost impossible to distinguish them from that formation in place. In a few places, careful study of the extent and composition of a slide is important to the proper interpretation of the geology of the bedrock.

Alum Rock Landslide. A large and important slide occurs on the north slope of Alum Rock Canyon just west of the Alum Rock rhyolite. It is a heterogenous mass of soft bluish serpentine muck, intermixed with silt and gravel of the Santa Clara formation, and a few large boulders and blocks of Franciscan. It came from well up the north slope, and filled the canyon to at least the height of the railroad cut on the north end of the high cliffs of Oakland conglomerate at the mouth of the canyon. The stream probably cut rapidly through and removed all the finer material, leaving the larger boulders stranded. Such boulders, up to 15 feet in diameter are exposed along the road and in the railroad cuts at the north end of the conglomerate cliffs, and were at first mistaken for exposures of bedrock in place. One such boulder consisted of manganese oxides, and was for many years believed to be a meteorite. Similar boulders in landslides resting on conglomerate can be seen in the road cuts about a quarter of a mile farther up the canyon, just west of the steep narrow canyon which cuts through the rhyolite. On a narrow point across the creek northwest of the cliffs of conglomerate, there is a slide mass consisting of sheared soapy serpentine which rests on cross-bedded gravel and silt, and broken weathered Oakland conglomerate.

Oak Ridge Landslide. The most spectacular slide in the area is that which extends from the western edge of Oak Ridge into Arroyo Hondo. This recent feature has carried great blocks of Franciscan greenstone, sandstone, and chert more than a mile down the slope.

Alluvium

No attempt has been made to map or differentiate the subdivisions of the alluvium of the Santa Clara Valley. Data were collected from well logs, however, in an attempt to ascertain the depth of alluvial fill in the valley, and the nature of the bedrock surface. The deepest well on record is that of the San Jose Water Works at Seventeenth and Santa Clara Streets, which reaches a depth of 1,535 feet. The drillers log of this well (table 3) shows in the first 250 feet less than one quarter gravel; from 250 to 1,000 feet, about one third gravel; from 1,000 feet to the bottom, only a little gravel mixed with clay. Although such a log is inadequate geologi-

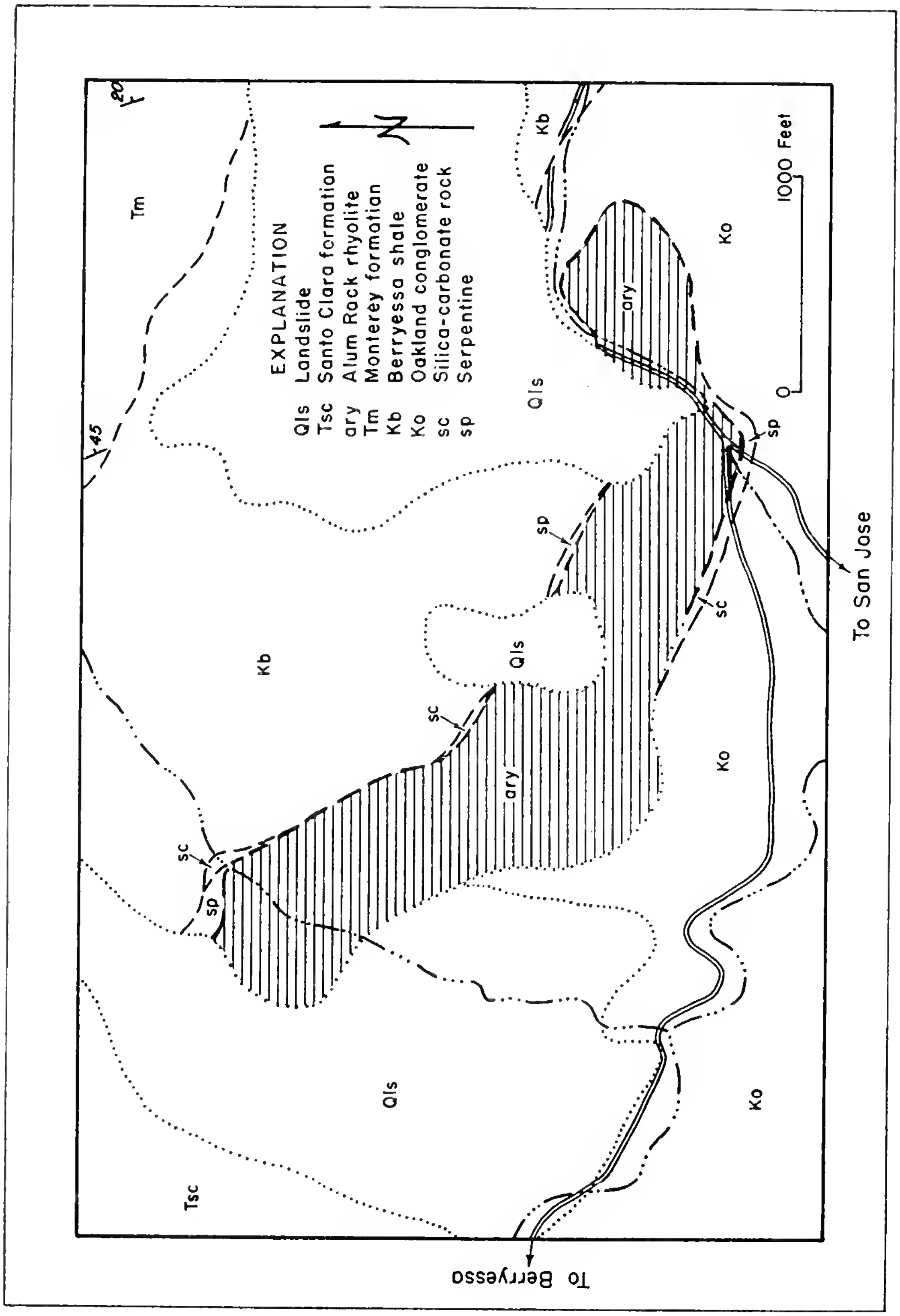

FIGURE 8. Map showing distribution of Alum Rock rhyolite

Table 3. Drillers log of San Jose Water Works, well No. 1, 17th and Santa Clara; drilled 1909, 1910.

0- 18 soil	500-506 yc	877- 890 bc and cem gr
18- 50 yc	506-514 bc	890- 895 yc and gr
50- 79 bc	514-523 yc	895- 939 bc
79- 89 gr	523-535 cem gr	939- 950 yc
89- 97 yc	535-537 yc	950- 952 yc and gr
97-115 gr	537-545 cem gr	952- 957 yc
115-130 bc	545-550 yc	957- 971 yc and gr
130-141 gr	550-552 cem gr	971- 980 yc
141-145 yc	552-568 bc	980-1005 yc and gr
145-150 gr	568-583 cem gr	1005-1035 bc
150-153 bc	583-587 yc	1035-1060 yc
153-189 yc	587-590 cem gr	1060-1072 yc and gr
189-206 gr	590-615 bc	1072-1130 bc
206-225 yc	615-620 yc	1130-1135 yc
225-255 bc	620-635 cem gr	1135-1145 bc
255-262 yc	635-673 yc	1145-1150 yc
262-273 cem gr	673-680 cem gr	1150-1190 bc
273-280 yc	680-700 yc	1190-1228 yc
280-287 cem gr	700-705 cem gr	1228-1232 yc and gr
287-292 yc	705-712 yc	1232-1240 yc
292-333 cem gr	712-717 cem gr	1240-1330 bc
333-355 bc	717-725 yc	1330-1360 yc
355-358 yc	725-735 cem gr	1360-1448 bc
358-386 bc	735-750 yc	1448-1469 yc
386-393 cem gr	750-760 bc	1469-1488 bc
393-402 bc	760-772 yc	1488-1495 yc
402-413 grey clay	772-777 cem gr	1495-1520 yc and gr
413-422 bc	777-791 bc	1520-1535
422-435 yc	791-809 yc	
435-446 cem gr	809-813 bc	
446-460 yc	813-850 yc & gr	
460-465 cem gr	850-855 bc (a boulder here)	
465-475 gc	855-865 bc	
475-495 bc	865-870 yc	
495-500 cem gr	870-877 bc	

ABBREVIATIONS
yc—yellow clay
bc—blue clay
gr—gravel
cem gr—cemented gravel

cally, it indicates a marked decrease in the amount of coarse material at a depth of about 1,000 feet. What the age of this material may be is entirely conjectural.

One of the most interesting features of the well log, from the standpoint of both structural history and sedimentation of the Santa Clara Valley, is that the bottom of the well is more than 1,100 feet below the present "threshold" of the valley at the Golden Gate.

Igneous Rocks

Alum Rock Rhyolite

The Alum Rock rhyolite is a body of intrusive igneous rock about 1,000 feet wide and 400 feet long which crops out in the lower Alum Rock Canyon. The most conspicuous exposures are in cliffs and talus slopes on the north side of the canyon opposite the Alum Rock Avenue entrance. It also forms the steep cliffs above the bridge where that road first crosses Penitencia Creek. It is intruded into the Cretaceous Oakland conglomerate and the Berryessa formation but a thin wrapping of serpentine has been carried up along the contact and locally has been altered to silica-carbonate rock. Although much of the contact is covered by landslide and talus, this relationship is visible in several places, and is particularly well exposed in the railroad cut at the extreme southern end of the mass. The rhyolite is bordered by silica-carbonate rock which grades outward into sheared green serpentine adjoining the conglomerate and shale. Northwest of this exposure the contact continues diagonally up the slope, marked by a low rib of silica-carbonate rock which continues until covered by the talus from the higher cliffs.

The rhyolite is mostly a strongly jointed fine-grained rock more or less silicified and stained by limonite. Fresh surfaces range in color from nearly white to brownish red or purple. Phenocrysts of albite up to 2 millimeters across occur in some phases of the rock. There are no ferromagnesian minerals. The entire rock when fused yields a glass with a refractive index of 1.485±, indicating a silica content of nearly 80 percent.[64]

Quite a different rock is exposed in the extreme northwest end of the body, where it is cut through by the steep gully, and in a few other places around the margin. This is a soft yellowish or greenish vesicular rock which contrasts strongly with the hard cliff-forming rhyolite. The general appearance suggests that it is a more basic rock than the rhyolite.

In general appearance and composition, the Alum Rock rhyolite bears a striking resemblance to the Leona rhyolite of the Oakland area.[65] However, the latter appears to consist of thick flows filling fault valleys along the mountain front, rather than of a single plug. In age, the intrusion is known only to be post-Cretaceous, but by analogy with the Leona, it is much more likely that it is post-Orinda and possibly Quaternary.

Andesite

In the fields and rolling hills just east of Silver Creek road 2 miles southeast of Evergreen is a long, narrow exposure of a fresh black glassy andesite with a pitchy luster and a porphyritic texture. It intrudes serpentine and appears to be overlapped by the Santa Clara formation. Its age is almost entirely a matter of conjecture, but the unusual freshness suggests that it is probably Quaternary. No other rocks like it are known within the area. A thin section of the andesite shows large, partly resorbed phenocrysts of oligoclase-andesine and smaller ones of colorless augite in a densely felted groundmass of feldspar microlites (andesine) and rounded grains of augite with interstitial brown glass.

STRUCTURE

The San Jose-Mount Hamilton area lies astride a complicated zone of folds and faults which form the western margin of the Diablo Range. The great northwest-trending Hayward and Calaveras fault systems are major features of the central Coast Ranges, extending many miles beyond the boundary of the area mapped. Although they are active faults, characterized by rift-type horizontal displacements, both of them coincide for some distance with older faults which have had a major part in delineating the larger structural units of the area.

Northeast of the Calaveras fault is a great area of Franciscan rock which is part of the core of the Diablo Range. Between the Calaveras and Hayward faults is the long, narrow block of folded Tertiary and

[64] George, William O., The relationship of the physical properties of the natural glasses to their chemical composition: Jour. Geology, vol. 32, no. 5, pp. 353-372, 1924.
[65] Lawson, A. C., op. cit. 1914.

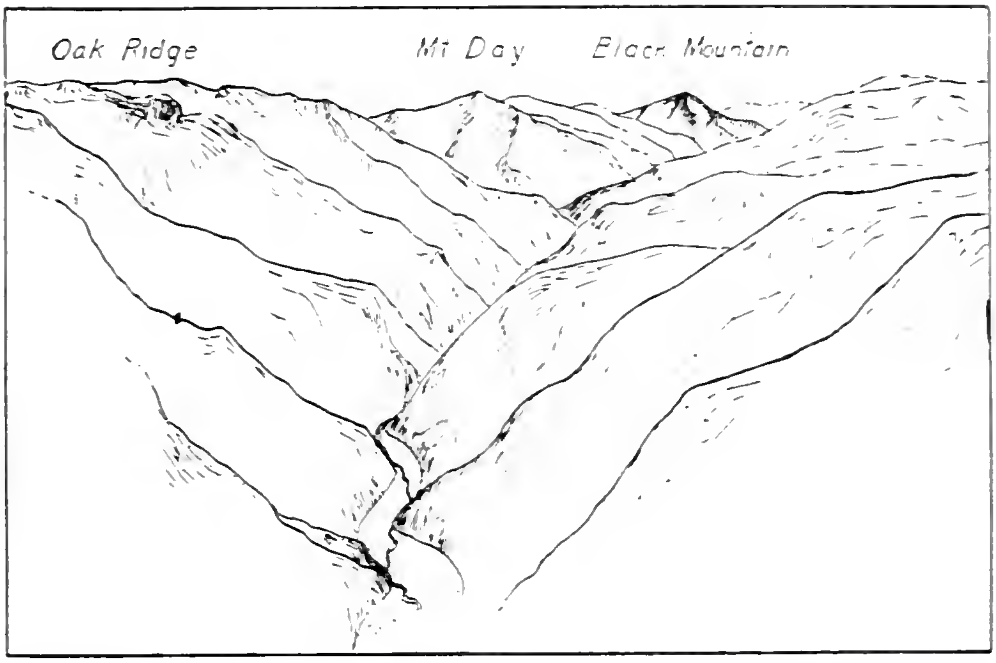

FIGURE 9. View of Arroyo Hondo from near its junction with Calaveras Valley. Older valley profile is preserved as benches along the canyon wall

Cretaceous sediments, here designated the Tularcitos block, which is the southeastern continuation of Mission Ridge and the Berkeley Hills. West of the Hayward fault, beneath the alluvium of the Santa Clara Valley, is another area of Franciscan rocks, the Santa Clara Valley block, which extends northwestward beneath the bay of San Francisco.

The largest and most conspicuous fold of the area is in the Tularcitos block and is designated the Tularcitos syncline. This structure can be traced from Niles in Pleasanton quadrangle at least to the edge of the Morgan Hill quadrangle. For much of this distance it is overturned to the southwest and is involved in the complex faults of the Calaveras system. The most recent movements in this zone have offset the fold, and the amount of offset is the best measure of the horizontal displacement along the fault. Folding within the areas of Franciscan rocks is not so well known, but undoubtedly there are folds as large as this or larger. One great syncline appears to extend the length of the area mapped, just east of the Calaveras fault. East of it, however, the structure becomes confused and consistent axes could not be traced with certainty.

Faults

Calaveras Fault System

The dominant fault of this area is the complex series of fractures known as the Sunol or Calaveras fault. From Sunol and Calaveras Valleys it can be traced northward through the Pleasanton quadrangle, the Concord quadrangle (where it was called the Franklin fault by Lawson [66]), and into the Carquinez quadrangle. On the geologic map of California [67] it is shown as far north as Port Costa on Carquinez Strait. Southeast of Calaveras Valley it forms a well-marked trench which contains Halls Valley and San Felipe Valley, and beyond the area mapped.

[66] Op. cit., 1914.
[67] California Div. Mines, 1938.

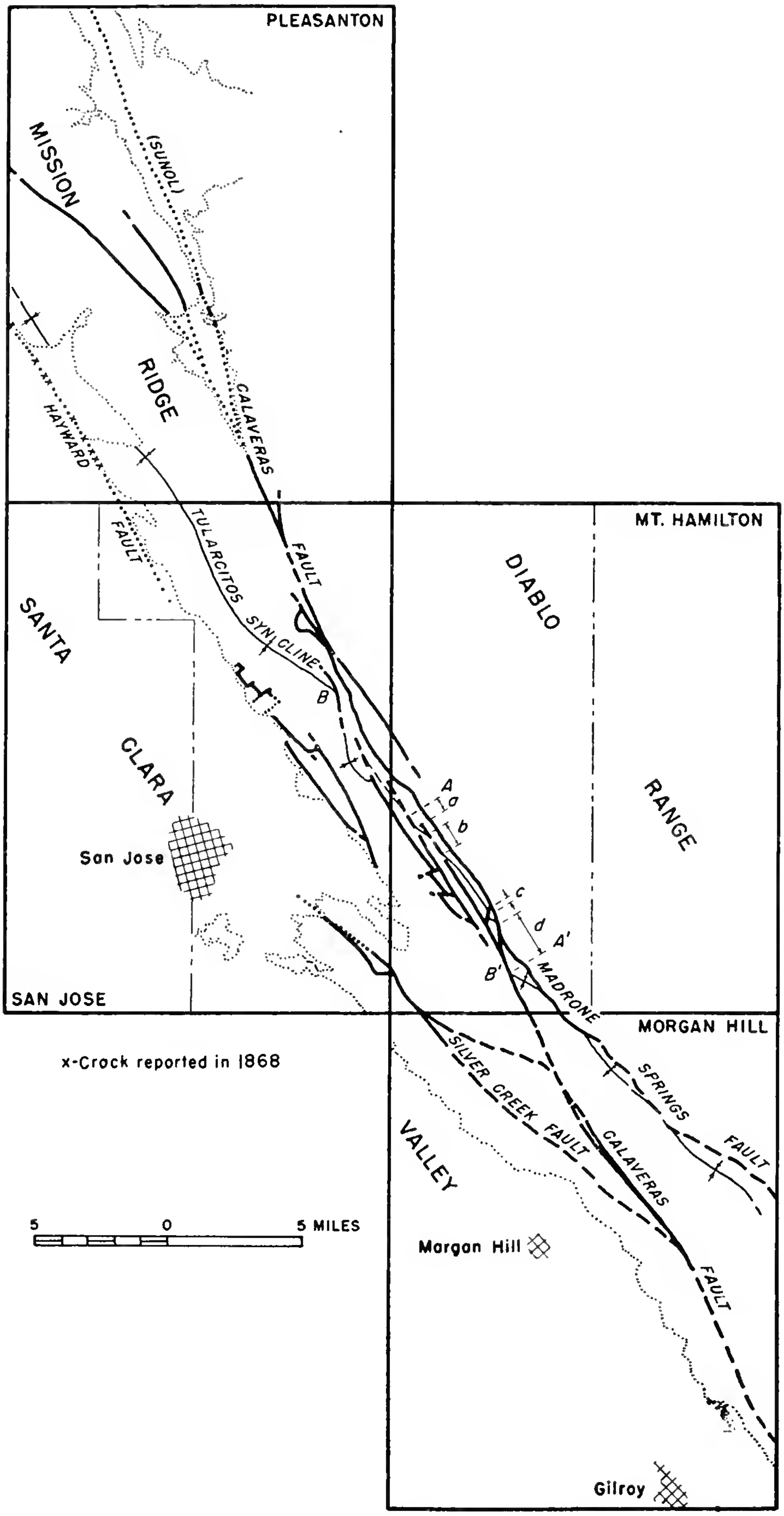

FIGURE 10. Structural features of the San Jose-Mount Hamilton area

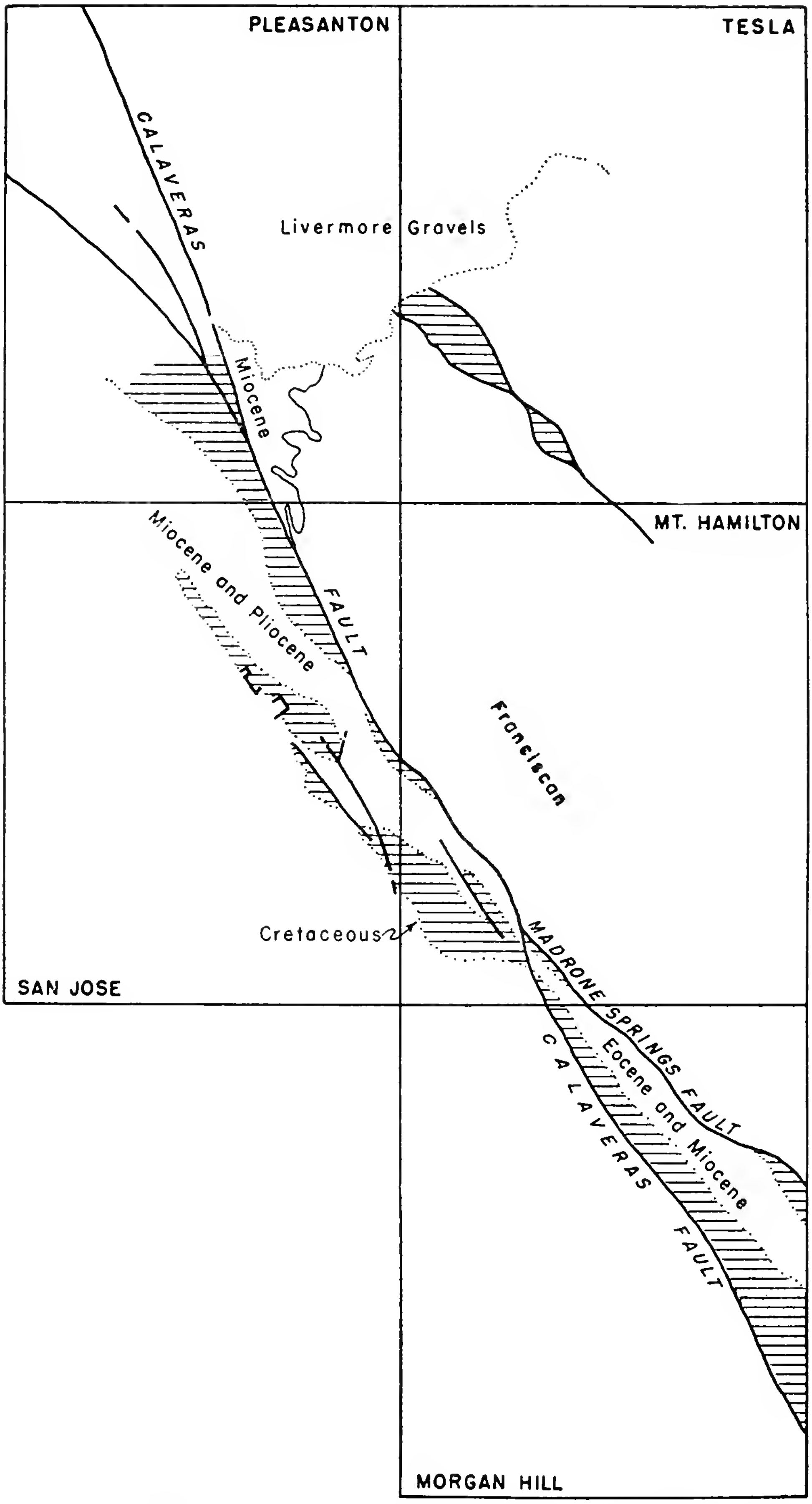

FIGURE 11. Map showing distribution of Cretaceous and Miocene rocks along the Calaveras fault zone

the valley of Coyote Creek in the Morgan Hill quadrangle. It emerges from the hills just east of Gilroy, and for some distance is traceable along the east edge of the Santa Clara Valley. It disappears beneath alluvium northwest of Hollister, but N. L. Taliaferro [68] reports that faults aligned with it continue still farther southeast.

The straightness of the Sunol-Calaveras fault has been commented upon by Vickery [69] and others, and in a generalized way the linearity is indeed remarkable. In detail, however, many irregularities appear, particularly if the faults required or demonstrated by stratigraphic evidence be considered; these are dominantly older planes within the system. In several places there is physiographic evidence of faults which appear to take "short cuts" and thus straighten the zone of movement. Such is the case between Los Buellis Hills and Halls Valley, where the fault separating the Franciscan from the rocks of Cretaceous and Tertiary age bends westward, and a new fault has developed within the Franciscan rocks east of the Haskins triangulation station. Earthquake epicenters which fall within 2 miles of this fault were recently tabulated for a 4-year period by Louderback [70] and indicate clearly that it is one of the active faults of the area. There have been no actual displacements within historic time, however, and the character of the most recent movements can be determined by interpretation of physiographic features along the fault. Within the area mapped, there is no evidence of systematic vertical displacements, though there are several places where sliver-like blocks within or parallel to the zone show differential elevation or tilting. Recent horizontal displacements along the fault zone are suggested by deflection of stream patterns in a few places, but these features are not as well developed as they are along the San Andreas fault.

The most significant systematic recent displacements on the Calaveras fault zone are horizontal movements analogous to those which occurred on the San Andreas fault during the 1906 earthquake, in which the southwest side of the fault moved toward the northwest. Although no such movements have occurred on the Calaveras fault within historic time, the displacements are in this direction, and it is possible to measure their cumulative effects since the development of the Tularcitos syncline. The synclinal axis crosses the fault zone at a low angle within the area mapped, and the total displacement since the folding is the summation of the individual displacements on faults within the zone. This distance amounts to about 3 miles.

Throughout most of the distance mapped, the horizontal displacements are concentrated in a fairly narrow zone, but between Halls Valley and San Felipe Valley, the displacements are distributed over several faults in a zone a mile wide. These faults have affected mostly the western limb of the Tularcitos syncline, and their continuity and relation to other faults of the Calaveras zone is uncertain because they could not be traced through the Briones sandstone west of Halls Valley.

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[68] Oral communication.

[69] Vickery, F. P., The structural dynamics of the Livermore region: Jour. Geology, vol. 33, p. 610, 1925.

[70] Louderback, George D., Characteristics of active faults in the central Coast Ranges of California, with applications to the safety of dams: Seismol. Soc. America Bull., vol. 27, pp. 1-27, 1937.

Older Faults of the Calaveras Zone

Evidence for large pre-Miocene vertical displacements on the Calaveras fault zone was recognized long ago by C. F. Tolman and F. P. Vickery.[71] Near Calaveras Dam, the lowest Miocene beds (Monterey) west of the fault rest on at least 2,000 feet of Cretaceous sandstone and shale (see section A-A', pl. 3) of which the base is not exposed; east of the fault, the Cretaceous is absent and the lowest Miocene beds (Temblor) rest directly on the Franciscan. The contact of the lowest Miocene beds with the Franciscan formation has been followed northward several miles into the southeast corner of the Pleasanton quadrangle,[72] where it is finally overlapped by the Livermore gravels. However, 3 miles to the northeast in the Tesla quadrangle, the Cretaceous is again present, faulted into the Franciscan between the Williams and Valle faults. Thus it appears that the Cretaceous was stripped from a narrow block of Franciscan rocks between the Calaveras and Valle faults before the Miocene period. It is uncertain how far to the southeast the Cretaceous was removed. Where Miocene rocks again appear east of the Calaveras fault in the Morgan Hill quadrangle, they rest on both Eocene and Cretaceous.[73] Thus if there were pre-Miocene post-Cretaceous movements in this area they must have taken place east of the Madrone Springs fault. In the Hollister quadrangle,[74] and the Quien Sabe quadrangle,[75] Miocene volcanics overlap a similar fault, resting directly on the Franciscan to the east, and on a thick section of Cretaceous to the west. The same zone of faulting continues through the San Benito quadrangle.[76] Thus there is evidence of strong post-Cretaceous pre-Miocene faulting along the west flank of the Diablo Range for a distance of at least 75 miles. This older fault coincides with the present Calaveras fault for about 20 miles.

The next movements on the Calaveras fault zone were undoubtedly post-Miocene, and probably post-Orinda. From Calaveras Reservoir to San Felipe Valley, the Franciscan was thrust westward over the Tularcitos syncline in a steep reverse fault. Throughout part of this distance the fault can be mapped rather closely, and a steep east dip is indicated by deflections as it crosses canyons such as Alum Rock and Arroyo Aguague. Southeast of San Filipe Valley this fault leaves the Calaveras zone, and when thus distinct, it is termed the Madrone Springs fault. It has been traced for a distance of 10 miles in the Morgan Hill quadrangle, and was observed in the Gilroy Hot Springs quadrangle some 7 miles farther southeast. Northwest of the Calaveras Reservoir, the post-Miocene uplift east of the fault dies out, and the axes of the folded Tertiary beds plunge northward beneath the Livermore basin.

Hayward Fault System

The Hayward fault is another of the major features of the San Francisco Bay area. It is known with certainty to extend from north Berkeley at least to the north edge of the San Jose quadrangle. Along the foot of the Berkeley Hills it forms a shallow trench clearly shown on the San Francisco folio.[77] It emerges from the hills near the town of

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[71] Op. cit., p. 611.
[72] Harding, J. W., op. cit.
[73] Gilbert, Charles M., op. cit.
[74] Taliaferro, N. L., Geologic map of Hollister quadrangle: California Div. Mines Bull. 143, pl. 1, 1949.
[75] Leith, Carlton J., Geology of the Quien Sabe quadrangle, California: California Div. Mines Bull. 147, pl. 1, 1950.
[76] Wilson, Ivan F., op. cit., pp. 256-257.
[77] Lawson, A. C., op. cit., 1914.

Hayward, and from there south lies along the foot of the hills just under the edge of the alluvium. It is an active fault whose movement was responsible for the destructive earthquakes of 1868 [78] and 1836.[79] According to the testimony of residents of the area who were questioned in 1906, there were fissures in the ground at many places from San Leandro to Aguague Caliente Creek near Warm Springs. It was agreed by residents of the area east of San Jose (Berryessa and Milpitas) that cracks did not extend that far south.

The systematic offsets of small streams along the Hayward fault indicate unmistakeably that the Santa Clara Valley block has moved northwest with respect to the mountain block, and Russell [80] has verified the existence of such offsets as far south as Niles. There is a well-developed linear scarp extending southeast from Irvington into the San Jose quadrangle near Warm Springs, but at Scott Creek the foot of the mountain swings eastward away from that line, and the linearity of the mountain face becomes less apparent. South of Scott Creek, there is no systematic offset of streams like that observed farther north. Thus both direct evidence and fissuring and physiographic evidence of horizontal offset suggests that the active fault dies out or goes beneath the alluvium of the valley a short distance south of Warm Springs.

Quaternary (post-Pliocene) vertical displacements on or near the line of the Hayward fault are mentioned by Lawson [81] and Buwalda.[82] Both these writers agree the west face of the Berkeley Hills is a degraded fault scarp, but Buwalda [83] has pointed out that the amount of vertical movement varies greatly along the strike, ranging from several hundreds of feet near Berkeley to almost nothing near Piedmont. A similar variation is evident to the southeast. Along the foot of the hills between Hayward and Niles, a low west-facing fault scarp of Recent origin is visible at the foot of the older degraded scarp. However, an east-facing scarp 20 to 25 feet high crossing the alluvial cone of Alameda Creek between Niles and Irvington has been described by Clark.[84] Southeast of Irvington there is again a well-formed west-facing scarp as much as 200 feet high consisting of unconsolidated Santa Clara formation. The recent origin of this feature is indicated both by the age of the sediments (lowest Pleistocene) and the relatively small amount of erosion which is evident even in the unconsolidated material.

Older Faults of the Hayward Zone

Throughout most of the distance shown to be recently active, the Hayward fault coincides with an older fault of great magnitude which separates the Santa Clara Valley block from the Tularcitos block. The evidence for this fault is largely stratigraphic and depends upon the absence of the Cretaceous and Tertiary rocks of the Tularcitos block from the Santa Clara Valley block. Buwalda [85] believes that the sedi-

[78] Lawson, A. C., and others, The California earthquake of April 18, 1906: Rept. State Earthquake Inv. Comm., Carnegie Inst. Wash. Pub. 187, vol. 1, pt. 2, 1908.
[79] Louderback, G. D., Central California earthquakes of the 1830's: Seismol. Soc. America Bull., vol. 37, no. 1, 1947.
[80] Russell, R. J., Recent offsets along the Hayward fault: Jour. Geology, vol. 34, pp. 507-511, 1926.
[81] Lawson, A. C., op. cit., 1914.
[82] Buwalda, J. P., Nature of the late movements on the Hayward rift, central California: Seismol. Soc. America Bull., vol. 19, pp. 187-199, 1929.
[83] Op. cit., p. 194.
[84] Clark, William O., Ground water in Santa Clara Valley, California: U. S. Geol. Survey Water-Supply Paper 519, 1924.
[85] Op. cit.

ments were deposited across or at least on the margin of the block, and were recoved by erosion resulting from local uplift. In the San Jose area, this movement is certainly post-Miocene and is probably post Mio-Pliocene (Orinda).

Although the Recent movements coincide generally with this older fault line, they do not do so in detail. Lawson[58] has noted that in the Hayward quadrangle the horizontal "rift zone" lies at the foot of the hills, but the older faults which separate the block underlain by Franciscan rocks from the block underlain by Cretaceous rocks are farther back in the hills near Lake Chabot. In the San Jose quadrangle, this older fault is exposed for a short distance near Berryessa. Along the line of section B-B′, plate 2, serpentine crops out west of the fault in contact with Oakland conglomerate of Cretaceous age. The old northwest-trending fault has been offset by several cross faults and is partially covered by the Santa Clara formation. The southernmost exposures of serpentine are in a small creek cut through the Santa Clara formation 0.8 of a mile north of the line of section C-C′ (pl. 2). Apparently the serpentine is terminated by another cross fault just south of this exposure. Although the Alum Rock rhyolite has brought up some serpentine around its margins, it is clearly intruded into the Cretaceous. The origin of this rectilinear pattern of offsets is obscure. The cross faults do not offset the base of the Monterey formation, and consequently must be pre-middle Miocene in age. Their effect on the Oakland conglomerate-Berryessa formation contact is mostly obscured by the mantle of Santa Clara formation and landslides, but the distribution of these Cretaceous rocks suggests that they may be affected somehow, though not by simple cross faulting. South of Alum Rock Canyon, there is no consistent physiographic evidence of recent movements nor is there stratigraphic evidence of an ancestral Hayward fault anywhere along the mountain front east of Evergreen. In this area, both movements have been effective along another zone of faulting following Silver Creek.

Silver Creek Fault

Another major fault zone is exposed along Silver Creek south of Evergreen. Its course is well marked by both physiographic and stratigraphic features southeast into the Morgan Hill quandrangle where it joins the Calaveras fault. This structure has been regarded as a continuation of the Hayward fault by most writers. However, it is 14 miles from Scott Creek near Warm Springs where the Hayward fault is last known. Its strike where exposed here is about N. 45° W.; that of the Hayward fault is about N. 30° W., and there is no consistent pattern of stream offsets like those which characterize the Hayward fault. For these reasons this fault zone is separately designated the Silver Creek fault. In the Silver Creek quicksilver mining district, are two dominant faults in the zone, enclosing a sliver-like area of Packwood gravel. The block to the west is dominantly serpentine and Franciscan; that to the east is serpentine and Knoxville. To the south the two faults unite, and the sliver of Packwood gravel is pinched out. It reappears again at the south edge of the mapped area, the easternmost fault of the zone swings sharply eastward, the westernmost fault continues southward, exposing almost 4,000 feet of the gravel. The attitude of the western fault of this

[58] Op. cit., 1914, p. 17.

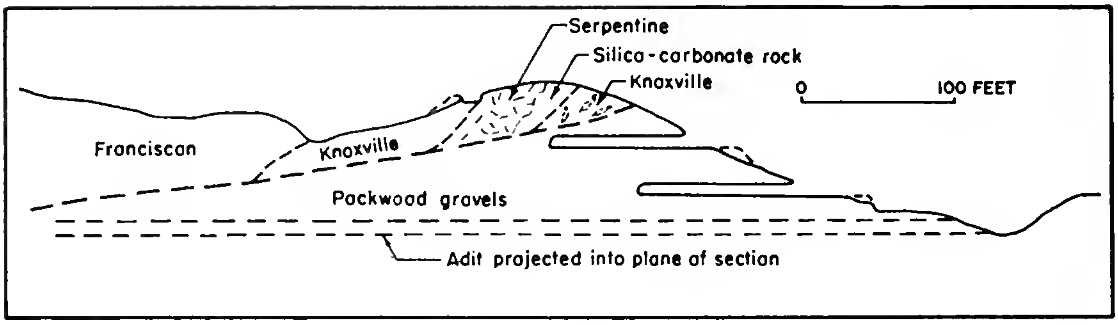

FIGURE 12. Section through Silver Creek fault zone, along line E-E′, plate 2

zone appears to be rather flat from its topographic expression, and two small accessible adits, though they do not penetrate the fault, indicate that it must dip 20° or less. Mr. Salvatore, who was foreman during the mining operations, reports that a 3,500-foot adit was driven west at about the level of the creek, and was in gravel for 800 feet. Also that shafts sunk in the serpentine west of the creek penetrated gravel. Although such a flat fault is most unusual in this area, all the information is consistent with its existence. To the south, however, the dip is much steeper; the west fault dips 65° W., where exposed in a prospect pit just north of Metcalf road in the Morgan Hill quadrangle. Here also, it is clear that the serpentine has been thrust eastward over the gravel.

The eastern fault of this zone also appears to be a reverse fault, though the evidence for an east dip is much less convincing. In fact, near the Silver Creek mine it is completely obscured by landslides of serpentine. Only the general relations to the topography suggest a steep east dip. Just north of the mine, the Packwood gravels are in contact with the serpentine and dip into it. The northwestward extent of this fault zone is unknown. A possible continuation is suggested by two earthquake epicenters which are about on the line of the fault beneath the alluvium of Santa Clara Valley.

Other Longitudinal Faults

Other faults parallel to the regional trend of the Coast Ranges appear near the front of the range south of Alum Rock Canyon. One of these, which was called the Clayton fault by Vickery,[87] extends from the mouth of Alum Rock Canyon south about 2 miles to the Mount Hamilton Road. Throughout this distance, the upper member of the Monterey formation dips eastward into the Cretaceous Oakland conglomerate. After an offset to the east about half a mile, the fault continues southeast mostly within the Briones formation, except for one small exposure of Monterey and Berryessa. The continuation of this fault farther south across the foot of Quimby road, connecting the offset of the Monterey formation north of the road with the small exposure of Monterey at the foot of the landslide west of the Hendricks Ranch is uncertain. The displacement on this fault, as mapped, is down on the west throughout its length.

Displacement on a smaller fault west of the Clayton fault is down on the east. At several places along these faults, bodies of silica-carbonate rock appear. These are derived from thin lenticular masses of serpentine which have been squeezed up in a semi-plastic state, and subsequently altered by hydrothermal solutions.

[87] Op. cit., pp. 610, 623.

Extending both northwest and southeast from Masters Hill, at the summit of Quimby road, is a long narrow outcrop of the Monterey formation which is bounded on the west by the Masters Hill fault for almost its entire length. The structure along the fault is obscure, but suggests that a hinge motion must have occurred. At the north end of the exposure of Monterey, there is a downthrow on the west of about 2,000 feet. At the south end of the strip of Monterey, south of the cross faults, a downthrow on the east is indicated by both the strike of the Monterey and the amount of Berryessa formation cut out. Monterey formation dipping into the Berryessa indicates that there is also a fault at the east side of this band.

Faults East of Calaveras Dam

The outcrops of Miocene rocks east of the Calaveras Reservoir are cut by many small faults. Their close spacing and complicated pattern are characteristic of many Recent faults in the Franciscan formation for which there is no statigraphic control.

Cross Faults

In several places the sedimentary contacts on the longitudinal faults are sharply offset by small faults which strike nearly at right angles to the regional trend. Several are mapped on Mission Ridge east of Warm Springs. Those which offset the serpentine may be older than the cross faults which affect the Tertiary rocks. The Monterey contacts and the Masters fault are offset by several such faults.

Folds

The block of Tertiary and Cretaceous sediments between the Hayward and Calaveras faults is dominated by a single fold, the Tularcitos syncline. This structure extends diagonally across the mapped area and continues for some distance into the adjoining areas. It is best exposed on Rancho Tularcitos near the north boundary of the San Jose quadrangle, where it is overturned; its axis dips about 55° E. The west limb is simple, but in the vicinity of Weller Road, the east limb contains several smaller folds. In the vicinity of Alum Rock Canyon, the axis of the syncline approaches the Calaveras fault zone, and the east limb has been partly obliterated by the thrust. To the south, the axis swings south parallel with the fault for about 3 miles, then turns east and is offset by the Masters Hill fault, and faults of the Calaveras zone.

The Franciscan formation east of the Calaveras fault is broadly folded, but only the larger structures were determined because of the lack of stratigraphic units. The most persistent and well-developed fold in the area is an open broad syncline whose axis is about parallel with the Calaveras fault for most of its length. East of this fold, the attitudes are consistent over small areas, but no continuous folds were traced. In general, the structural trends of the Franciscan appear to be north to northwest, as indicated by dips and the few outcrops of chert and serpentine. However, on the slopes of Mount Hamilton, Sulphur Creek, and the ridge to the south, east, and northeast, strikes are common, and it seems possible that they may represent a period of compression in a direction almost normal to that responsible for the most conspicuous folds. Evidence of this was also observed by Wilson [88] in the San Benito quadrangle.

[88] Op. cit., pp. 257-258.

Periods of deformation in the San Jose-Mount Hamilton area.

Age	Type of deformation	Area affected
Eocene? (post - Cretaceous, pre-Miocene)	Block faulting	Western margin of Diablo Range
Between middle and upper Miocene	Gentle folding	Tularcitos block
Near end of upper Miocene	Strong folding	Diablo and Santa Clara Valley blocks of Franciscan uplifted
Between early Pliocene and earliest Pleistocene	Extreme compression	Tularcitos block strongly deformed; folds overturned, Diablo block thrust westward over trough
Pleistocene	Reverse faulting	Older rocks thrust over Packwood gravels
Recent	Faulting	Uplift of Diablo Range; downwarp of Santa Clara Valley; horizontal movement on Hayward and Calaveras faults

Structural Dynamics

Structures in the San Jose-Mount Hamilton area range in age from pre-Miocene to Recent. The Calaveras fault has formed in part along an ancestral fault which shows pre-Miocene displacements of large magnitude. Locally at least, the post-Miocene movements are in a reverse direction. Basins of deposition extended across the course of the present Calaveras rift during the Eocene,[89] and again in the Miocene. These basins were later compressed into folds whose axes cross the course of the rift faults and have now been offset by them. There is clear-cut physiographic evidence that these features are younger than the folding and the ancestral faults. The rift-type faults are characterized by an alignment of valleys and saddles of recent consequent development, and by transverse or tributary streams which are actively adapting to continued horizontal movements. The older faults cut indiscriminately across valleys and hills.

The complicated structural history of an area such as this indicates that the pattern of stresses responsible for its development has varied in both time and space. There is evidence of periodic compression of the central Coast Ranges, in a direction varying from N. 40° E. to N. 60° E., which began in the early Tertiary, and reached a culmination in the late Tertiary or early Quaternary. Since that time, a new pattern of regional stress has developed, in the form of a clockwise couple. The rift-type faults which have developed in response to this pattern followed older lines of weakness where available, and thus the Hayward and Calaveras faults, like the San Andreas, coincide in part with the boundaries of older structural units.

[89] Gilbert, C. M., op. cit., 1943.

GEOLOGIC HISTORY

Jurassic. The earliest event recorded in the San Jose-Mount Hamilton area is the deposition of the Franciscan formation in the late Upper Jurassic. This area was apparently near the center of a broad slowly sinking geosyncline in which were deposited at least 10,000 feet of arkosic sandstone and shale, and small amounts of conglomerate and limestone. Local submarine volcanism produced basaltic and spilitic lavas, and contributed silica, iron, and manganese to form radiolarian cherts which are interbedded with the clastic sediments. Near the close of the Jurassic, the rate of deposition decreased, and the fossiliferous shales of the Knoxville were deposited. Volcanism was local and unimportant. At about this time also, large sills and dikes of serpentine and smaller bodies of gabbro, diabase, and diorite were intruded into the wet fresh sediments.

Diablan Orogeny. The marked orogeny which affected many parts of the Coast Ranges at the close of the Jurassic is reflected in the San Jose-Mount Hamilton area by a sudden change in the character of the sediments rather than by actual folding.

Cretaceous. The lowest Cretaceous deposits are the massive coarse Oakland conglomerate, which gives evidence of strong local uplift of part of the area contributing sediment to the Coast Range geosyncline. With the wearing down of this source, sediments again became finer, and the sandstone and shale of the Berryessa formation were deposited. The existence of Upper Cretaceous deposits in this area is uncertain.

Cretaceous-Miocene Interval. The absence of deposits of Eocene age makes it impossible to outline in detail the events which took place during this interval. There was strong uplift of the western margin of the Diablo Range by faulting; and from evidence in adjoining areas, one or more periods of folding are known. The western edge of the Diablo Range may have been exposed during much of this time, because the entire sequence of Knoxville and Cretaceous rocks was stripped off by middle Miocene time.

Miocene. The middle Miocene seas appear to have transgressed across the trough from the west, depositing the chert and foraminiferal siltstones of the Monterey formation. At their maximum, the seas extended across the present Calaveras fault onto the edge of the Diablo Range.

Between middle and upper Miocene, the area was uplifted and the middle Miocene deposits were exposed and eroded from the Cretaceous locally.

Upper Miocene seas transgressed farther across the area inundated earlier, and deposited the Briones sandstone on both the Monterey and the Berryessa formations. Abundant fossils and conglomeratic sandstones indicate a persistent shallow marine environment. Heavy minerals suggest a possible admixture of Sierran as well as Coast Range sources.

Post-Briones Orogeny. Strong folding, uplift, and erosion of large areas of Franciscan were initiated at this time. It seems probable that both the Diablo Range and the San Francisco Bay block may have been elevated.

Mio-Pliocene. The maroon, purple, or green conglomerate, sand, and clay of the Orinda were deposited under flood-plain conditions. Its rapid variation and diversity suggest that sources were local and erosion rapid. There is a marked increase in the amount of Franciscan debris.

Post-Orinda Orogeny. After the deposition of the Orinda, the convulsive orogenic episode began, which destroyed the Pliocene basins, and resulted in tight or overturned folds, and strong elevation of older mountain blocks by outward thrusting over adjoining basins. Uncertainty concerning the age of the Orinda, and absence of younger beds makes it impossible to fix the age of this deformation more closely than sometime within the Pliocene. Evidence from nearby areas indicates that it may have had several phases extending over much of that period, possibly into earliest Pleistocene.

Pleistocene. During the Pleistocene the newly uplifted areas were rapidly eroded, and the thick heterogenous Packwood gravels were dumped in orogenic troughs. Faulting continued, and the overthrusting of these gravels by older rocks. Uplifting of the Diablo Range and Berkeley Hills continued, and downwarping of the San Francisco Bay block and the Santa Clara Valley basin. Mountain blocks were eroded to low relief, and the older alluvium was deposited in Santa Clara Valley basin. Horizontal displacement began on Hayward and Calaveras faults.

Renewed uplift of Diablo Range occurred, and the Santa Clara formation was deposited in the Santa Clara Valley basin.

Uplift, which initiated the present cycle of erosion, took place.

ECONOMIC GEOLOGY

Quicksilver

Silver Creek Mine. The Silver Creek quicksilver mine is in sec. 33, T. 7 S., R. 2 E., M. D., 3.6 miles S. 36°E. of Evergreen. It is owned by James A. Slatore who lives on the property, and it was operated by lessees from December 1, 1942, to July 15, 1943.

The mine was first listed in the twelfth annual report of the State Mineralogist for the years 1893-94, and by 1903-04 was reported to have yielded quicksilver valued at $60,000. Several long adits were driven in 1906-08, but by 1918 operations had apparently been abandoned and no production was reported by Bradley in 1918.[90] The mine was operated from December 1, 1942 to July 1943, by Mr. Sam Cohen who produced 25 to 30 flasks of quicksilver. The ore-bearing zones were exposed by open-pit methods, and the ore was concentrated before burning by using a crusher, washer, and table. Considerable hand-picked ore was burned directly.

The mine is in the Silver Creek fault zone which consists of a narrow sliver of Packwood gravel, dropped down and overthrust from both sides by Franciscan, Knoxville, and serpentine. The eastern fault of the zone is a steeply dipping thrust whose contact with the gravel is completely obscured by landslides. The dip is inferred from the deflection of the fault as it crosses Silver Creek road, and from adits driven east at the creek level, which are reported to have been in gravel for 500 feet. The

[90] Bradley, Walter W., Quicksilver resources of California: California Min. Bur. Bull. 78, p. 168, 1918.

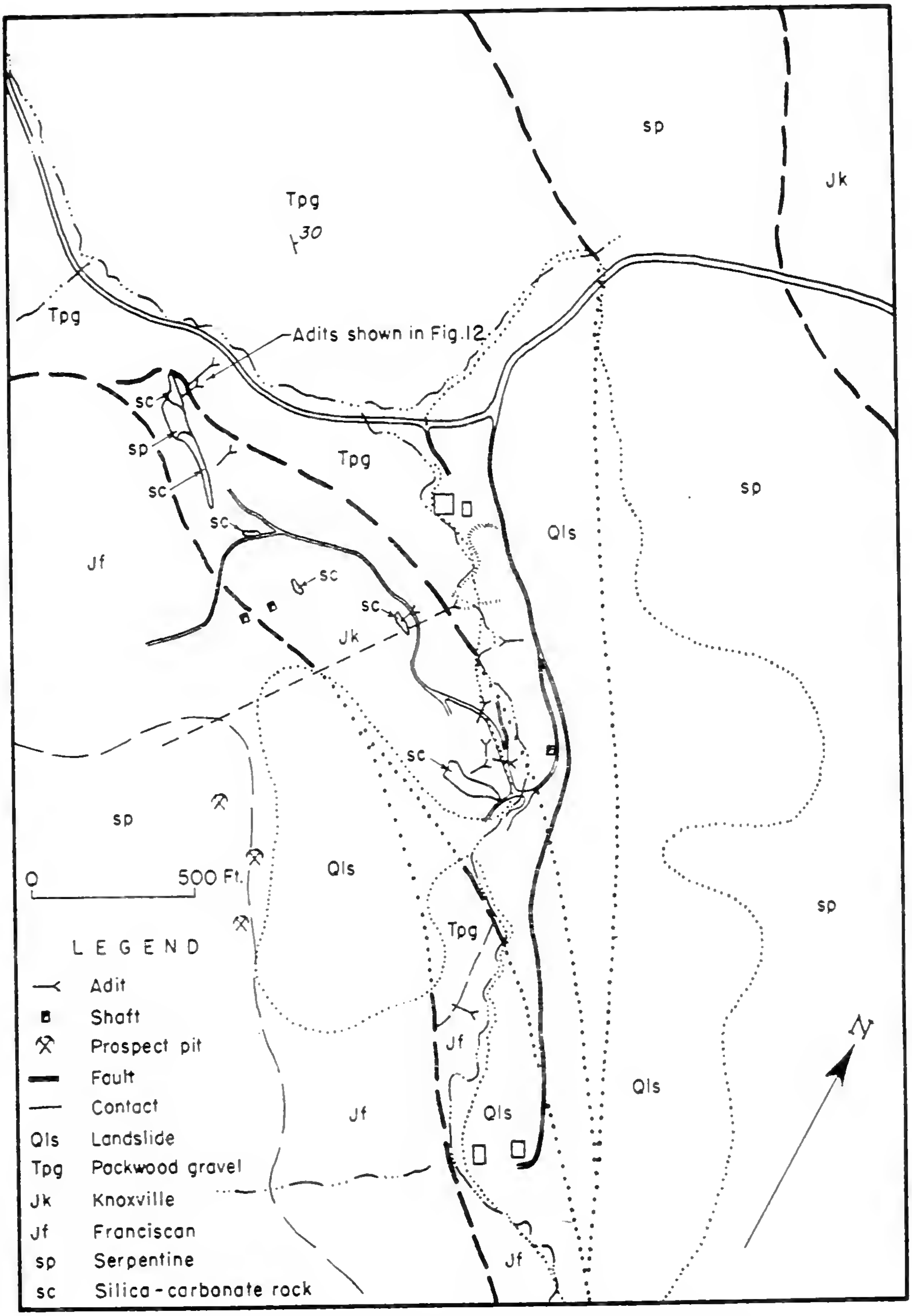

FIGURE 13. Geologic map of the Silver Creek mine area

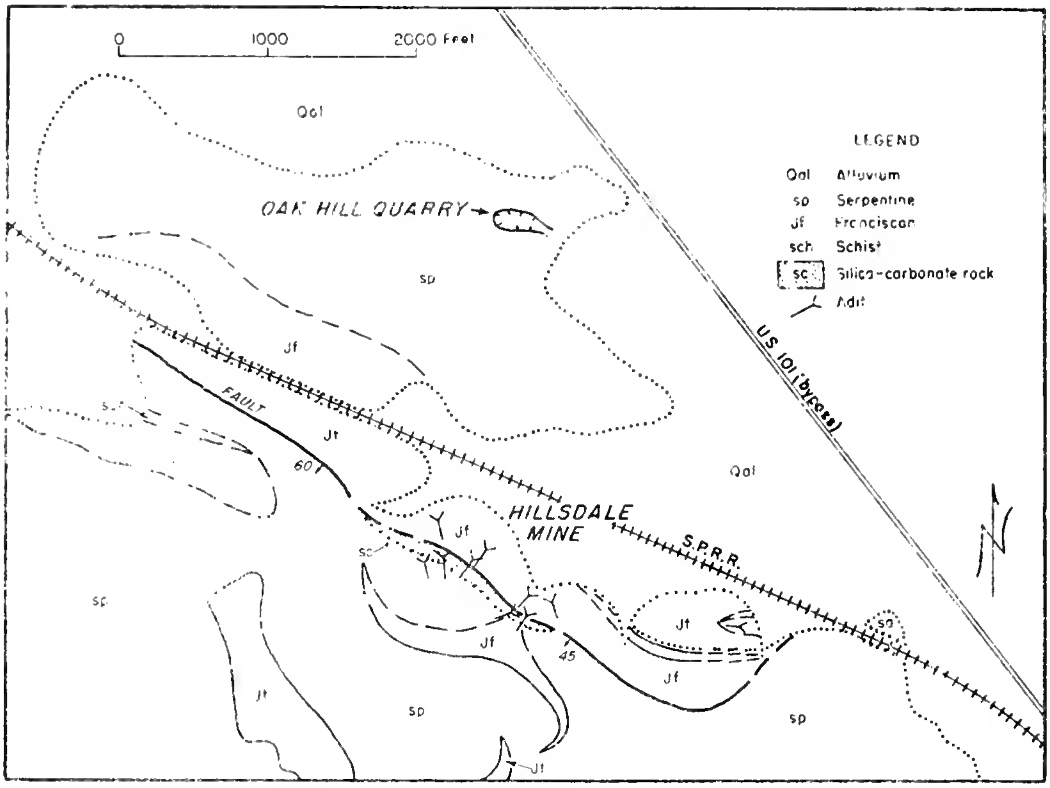

FIGURE 14. Geologic map of the Hillsdale mine area near San Jose

western fault of the zone is an unusually flat thrust on which Franciscan, Knoxville, and serpentine have been thrust eastward over the gravel for some distance. This fault crops out on top of the small ridge in which most of the development has taken place, but is not exposed in any of the accessible workings. Two small adits were mapped, however, which pass under the surface outcrop of the fault, indicating a maximum dip of about 30 degrees. The dip may be still flatter, however, inasmuch as Mr. Slatore reports that a long adit driven west at the creek level penetrated 800 feet of gravel before encountering serpentine and Franciscan. Shafts west of the surface outcrop are also reported to have encountered gravel at shallow depths.

The only exposures of ore in place are in a block of sheared and mineralized fossiliferous Knoxville formation containing several large bodies of silica-carbonate rock. These are distorted and broken by faulting and have no downward continuity. Much of the early production came from loose boulders of silica-carbonate rock in the creek bed, and the landslides which have come down both slopes.

Cinnabar is contained in small veins in this silica-carbonate rock, and in minute stockworks in the surrounding Knoxville shale and sandstone. During recent operations mineralized shale and residual surface material provided the greater part of the ore. Mining was done by open-cut methods; a bulldozer was used for stripping and moving waste.

Hillsdale Mine. The Hillsdale mine (also called Oak Hill, San Juan Bautista, Chapman or Chaboya) is on the east slope of the Oak Hills, 4 miles south of the city of San Jose. It was reported by Bradley [91] to have been discovered in 1847, and to have been worked intermittently from 1847-74, and from 1892 to 1907; a little work was done in 1915. It is

[91] Bradley, W. W., op. cit., p. 160, 1918.

owned by Mr. Manuel Lewis of San Jose, and was operated by several lessees during World War II.

There are said to be more than 4,000 feet of workings, but only a few of the adits are accessible; no underground mapping was done by the writer. The mine is on a prominent fault which strikes N. 50° W. and dips about 60° SW. The hanging wall is serpentine which contains several thin "leaves" of Franciscan sediments; the footwall is mostly Franciscan sandstone. The ore occurs in a thin band of silica-carbonate rock which has developed from the serpentine adjoining the fault. On the surface, this zone appears to be about 50 feet thick near the workings and to taper out completely both north and south. The principal workings are a series of adits which extend into the hill where the silica-carbonate rock is thickest. From the size of the dumps, it seems likely that the silicified zone has been explored for much of its length. The lowest adit is about 150 feet vertically below the highest outcrops.

The ore on the dumps consists of greenish-gray opalized serpentine cut by thin veinlets of chalcedony and veins of coarsely bladed dolomite. Cinnabar occurs with the chalcedony and sparingly with the dolomite. A few specimens show bituminous substances in vugs within the dolomite veins. Edgar Bailey of the U. S. Geological Survey reports that some of these veins consist of magnesite, not dolomite.

Smaller Mines and Prospects. A number of small abandoned mines and prospects were encountered in the Silver Creek Hills during the course of geologic mapping. The ownership and history of most of them have not been traced. Nearly all have been driven to explore bodies of silica-carbonate rock which occur on the serpentine-Franciscan contacts. Only one, the New North Almaden owned by the Jacob Miller heirs, has been worked recently.

Manganese

San Jose. Until 1918, a large boulder of manganese ore was exposed in the bank of Penitencia Creek in the lower end of Alum Rock Canyon. Locally it was regarded as a meteorite, and in fact was so labelled for many years. In 1918, it was removed and shipped for its manganese content by the City of San Jose. It yielded 329 tons of ore which contained 52.6 percent manganese. All that remains now of this interesting occurrence are some fragments of low-grade manganese oxide in the north bank of the creek just opposite the first bridge encountered in driving up the canyon.

The boulder was studied by Rogers,[92] who described its unusual mineralogy. The minerals originally identified by Rogers include tephroite, hausmannite, pyrochroite, ganophyllite, rhodochrosite, barite, and psilomelane. Later a new mineral, "kempite" was added to this list.[93] The boulder is not in place but is part of a tremendous landslide which covers the north slope of the canyon. It is surrounded by an incoherent mass containing debris of serpentine, Franciscan, Berryessa formation, and Santa Clara formation. Several boulders of serpentine, or altered Franciscan greenstone of comparable size are along the road and in the railroad cut nearby, resting on conglomerate. None of the manganese

[92] Rogers, A. F., An interesting occurrence of manganese minerals near San Jose, California: Am. Jour. Sci., 4th ser., vol. 48, pp. 443-449, 1919.

[93] Rogers, A. F., Kempite, a new manganese mineral from California: Am. Jour. Sci., 5th ser., vol. 8, pp. 145-150, 1924.

material has been found in place up the hill, and it seems probable that the manganese boulder was carried up with the serpentine along the borders of the Alum Rock rhyolite. The unusual assemblage of minerals present lends support to this hypothesis.

Wallace Ranch. A manganese prospect referred to as the Wallace Ranch [94] is in the SW¼SE¼ sec. 8, T. 6 S., R. 25 E., just east of Sierra Road. The workings consist of several small open cuts in which there is a little low-grade oxide ore derived from manganiferous chert.

Mateos Ranch. Manganese occurs also on the old Mateos Ranch, in sec. 8, T. 6 S., R. 2 E., in Alum Rock Canyon about 2 miles beyond the park. The ore is found in seams and pockets in chert. High-grade float is found in the canyon and 40 tons of ore was shipped from an open cut made in 1917.[95]

Miller Ranch. A manganese mine consisting of an open cut about 20 by 60 feet, and a partially caved stope and adit at a lower level is located on the old Miller Ranch, just below Sierra road on the extreme southeast point of Los Buellis Hills. The workings are in a band of red Franciscan chert only a short distance east of one of the older branches of the Calaveras fault.

No primary ore was observed in place, but fragments of ore on the dump of the open cut consist of rhodochrosite and hydrous manganese silicates coated with fresh black oxides. The fragments collected have a specific gravity of 3.8, and may contain 30 to 40 percent manganese.

Copernicus Peak. A little low-grade oxide ore derived from white manganiferous chert is exposed in prospect pits on the north spur of Copernicus Peak. Only a small amount of the material on the surface appears to contain 30 to 40 percent manganese.

Road Metal and Rip-Rap

The cherty middle member of the Monterey formation is quarried at many places in the San Jose-Mount Hamilton area for fill and road surfacing and is sold under the name "slag." It is particularly desirable because it can be quarried without blasting, and breaks into small fragments without crushing. The aggregate is angular; it does not disintegrate or decompose, and it packs under traffic to a hard surface. The location of established quarries is indicated on plate 2; however, similar rock is present at many other places, and the supply of this material is almost unlimited. Suitable material is present almost everywhere that the Monterey formation is exposed, and the location of additional quarries depends mostly on convenience and accessibility.

The Oakland conglomerate also has been used for road metal and fill, and has been quarried extensively at the mouth of Alum Rock Canyon, and at a few other places. It is equally resistant to weathering, but is coarser and more difficult to quarry.

The chert of the Franciscan formation is also used for this purpose, but to a more limited extent.

Rip-rap and coarse aggregate have been obtained from the quarry in Oak Hill south of San Jose. The rock obtained here is mostly gabbro

[94] Trask P. D., Wilson, I. F., and Simons, F. L., Manganese deposits in California—a summary report: California Div. Mines Bull. 125, p. 181, 1943.

[95] Trask, Parker D., and others, Geologic description of the manganese deposits of California: California Div. Mines Bull. 152, p. 254, 1950.

and diorite, mixed with serpentine. Much of this coarse material remains, but its extent appears to be limited to the area surrounding the present quarry. The rest of the hill consists of soft serpentine or Franciscan rocks.

Sand and Gravel

Sand and gravel have been obtained from the bed of Coyote Creek south of San Jose, and at a few other places. Such creek beds appear to be the best source of this material within the area mapped. The Santa Clara formation, though containing gravel, would require much more washing to obtain a clean product.

Ground Water

The ground-water supply of the Santa Clara Valley[96] is without doubt its most important natural resource. The alluvium of the basin is generally regarded as a complex series of alluvial fans which extended out from the canyon mouths and coalesced in the center of the basin. The changing pattern of their distributaries has been built into a three-dimensional network of aquifers extending out from the main stream canyons. This concept has recently been applied to the problem of replenishing the underground aquifers, by construction of percolation beds near the heads of such fans. Springs within the mountains have an important effect in delaying the runoff of winter rains, though they do not supply a large part of the water used throughout the valley. The largest springs are the result of well-defined structural and stratigraphic controls.

The upper Miocene Briones sandstone is the most important aquifer within the mountain areas. The folded beds of this unit in Monument Peak west of Calaveras Reservoir provide a large flow and make an important contribution to the Calaveras Reservoir the year round. The springs which are the largest in this area issue along the eastern slope of the range, at the Monterey-Briones contact. A similar condition exists west of Halls Valley, and on the west side of the range south of Alum Rock, but the flow is not so large. The Orinda and Briones formations in the Tularcitos syncline on the west slope of Monument Peak also accumulate large amounts of water which issue as perennial springs near the base of the slope. A number of small springs are found in the Oakland conglomerate east of Evergreen.

In the central part of Alum Rock Canyon the thermal and mineral springs have developed almost entirely within the permeable middle member of the Monterey formation. This unit is of relatively small importance as an aquifer, however.

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OLAF P. JENKINS, CHIEF

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

BULLETIN 157 PLATE 2

EXPLANATION

SYMBOLS

ROCKS

SEDIMENTARY ROCKS

Franciscan formation

IGNEOUS ROCKS

Andesite

Alum Rock rhyolite

Serpentine

Franciscan greenstone

Monterey formation

Berryessa shale

Oakland conglomerate (?)

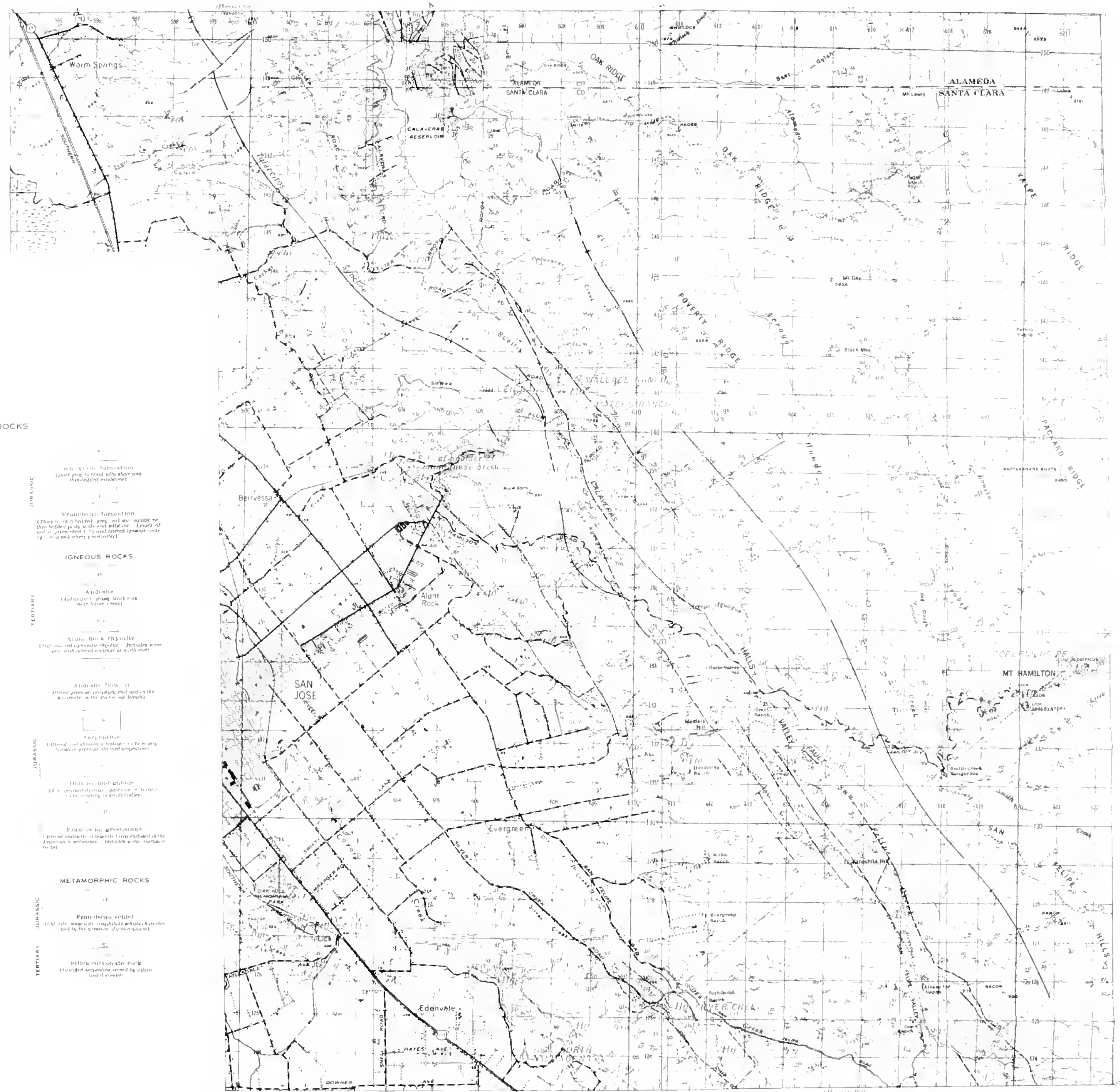
METAMORPHIC ROCKS

Franciscan schist

Silica carbonate rock

Mine

Mine adit



Geology by Max D. Crittenden, Jr., 1948

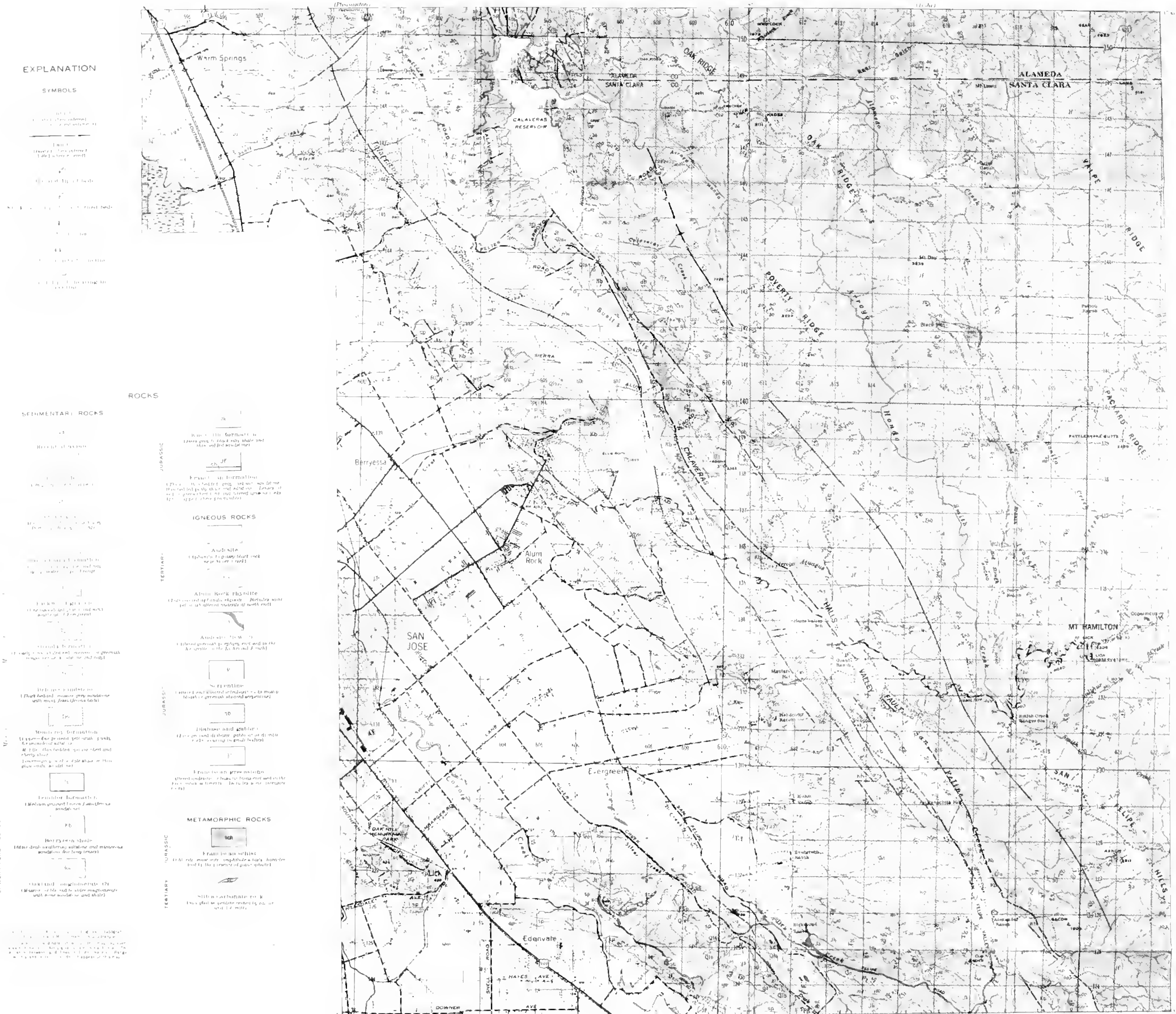
ECONOMIC MAP OF THE SAN JOSE-MOUNT HAMILTON AREA, CALIFORNIA

By Max D. Crittenden, Jr.

Scale $\frac{1}{62500}$

Contour interval 50 feet

Datum is mean sea level (1929 Adj.)



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